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May 31, 1991

Rich Steinmann
UBP-10
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400 7th Street, S.W.
Washington, D.C. 20590

Dear Mr. Steinmann :

I enjoyed meeting you on the 17th of ~~m~~ M ay on the occasion of presenting the development of the New York Model for the Regional Plan Association.

Enclosed please find published material on my earlier work on the Chicago model which led to the current work on New York. I am looking forward to the completion of the New York project.

Sincerely,

Alex Anas

THE CAPITALIZATION OF PUBLIC INVESTMENTS:

TRANSPORTATION INVESTMENT POLICY

Alex Anas

ABSTRACT

A model which endogenously determines travel and location demands, housing rental decisions and vacancies, and spatial equilibrium rents *given* a predetermined spatial distribution of employment and housing stock is developed.

The demand side is a nested multinominal logit model of joint residential location, dwelling, and commuting mode choice consistent with stochastic utility maximization. The supply side is a binary logit model of the decision to offer a dwelling for rent or keep it vacant consistent with stochastic profit maximization.

An aggregated form of the model is estimated using maximum likelihood econometrics and the 1970 transportation census data for Chicago. Prototype policy simulations with the estimated model are performed for the Chicago

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SMSA. The policy simulations deal with the impact of three proposed rail transit systems on equilibrium housing rent changes and the potential for raising part of the total cost of new rapid transit projects by placing an incremental tax on housing and thus taxing away the net appreciation in values.

I. INTRODUCTION

Nearly all public investments have major capitalization effects in the surrounding real estate market. The price of vacant land and buildings situated near such investments can increase or decrease depending on the type of investment.

Calculating the change in aggregate real estate values created by an investment amounts to estimating the producer surplus change created by that investment. The producer surplus change is as important a part of total benefits as the consumer surplus (or utility) change. No cost-benefit analysis of a public investment project can be complete without a proper accounting of these capitalization effects.

In some cases, increases in real estate values induced by a public investment can become the basis for appropriate incremental property taxes aimed at capturing the increased values and using these tax revenues to finance part of the investment's cost.

A case in point is transportation investment policy. These investments impact real estate values over large areas in a metropolis and can induce substantial mobility, adjustment, and reequilibration in the market for land and buildings. Therefore, models for estimating the impact of transportation systems on property values and housing prices in particular must simulate demand- and supply-side preferences in the housing market and the equilibration process which matches demand and supply.

In recent years the application of stochastic utility maximizing multinomial logit models to the problem of residential location and rental housing has been pursued by Quigley (1976), Lerman (1977), and Anas (1981). Theoretical aspects of the multinomial logit, nested logit, and generalized extreme value models have been explored by McFadden (1978). While the above contributions deal with the econometrics of demand estimation, papers by Anas (1979, 1980) and Anas and Lee (1981) have focused on the interaction of residential location demand and housing supply in a *tâtonnement* process in which housing rents respond to excess demands and are readjusted until the market is cleared.

The purpose of this paper is to develop, estimate, and apply to policy analysis a model of spatial price equilibrium in rental housing markets. This model takes the spatial distribution of employment and the housing stock as given and endogenously determines the travel and location demands of households and the housing rental decisions of landlords. To put it another way, equilibrium mode choices and the equilibrium allocation of households to dwellings are simultaneously determined.

The second section of the paper develops the demand side as a nested multinomial logit model of joint residential location, dwelling, and commuting mode choice consistent with stochastic utility maximization. The supply side is a binary choice model of the landlord's decision to offer the dwelling for rent or keep it vacant, consistent with stochastic profit maximization.

In the third section the existence, uniqueness, and stability of a Walrasian equilibrium based on the demand and supply sides of Section II is proved.

In section IV, aggregated forms of the models developed in Section II are proposed and estimated from 1970 census data for the Chicago SMSA.

Section V applies the estimated model to the equilibrium analysis of multimodal urban transportation policy for the Chicago SMSA, again using the 1970 census data. The specific policy question examined in this section is whether heavy rail projects proposed for Chicago's southwest corridor can be partly financed via an incremental special assessment tax on housing, an approach called "value capture policy" (see Sharpe, 1974). We show that 14 to 18 percent of the capital and operating costs of the heavy rail projects can be raised by taxing housing value increases within a corridor (special tax assessment district) surrounding the transit projects.

II. DEMAND- AND SUPPLY-SIDE MODELS: STOCHASTIC UTILITY AND PROFIT MAXIMIZATION

Let the metropolitan area consist of $i = 1, \ldots, I$ residential zones, and let each zone have $k = 1, \ldots, S_i$ rental dwellings. Let there be $h = 1, \ldots, H$ household segments, each household segment being identified by a specific workplace, and for simplicity, assume each household to have one employed member. The number of households in segment h are N^h. For each household to be assured of a dwelling, it must be true that $\sum_h N^h \leq \sum_i S_i$, namely, that the number of dwellings must be sufficient (some vacancies will normally exist). Let $m = 1, \ldots, M_i^h$ be the number of travel modes available to employees of segment h seeking to commute to zone i from the particular workplace of segment h.

The demand-side problem is one of utility maximization: Each household must choose the most preferred dwelling. Suppose that the utility function of a household in segment h is

$$\hat{U}_{imk}^h = U_i^h + U_{im}^h + U_{imk}^h + \varepsilon_{imk}^h , \tag{1}$$

where U_i^h is the part of strict utility which depends on zone only; U_{im}^h is the part of strict utility which depends on zone i and commuting mode m; and U_{imk}^h is the part of strict utility which depends on zone i, mode m, and dwelling k. Finally, ε^h_{imk} is the part of utility which is random and varies from household to household within segment h and for each (i, m, k).

The separability of the utility function shown in (1) and the assumption of utility maximization implies that we can compute P^h_{imk}, the probability that a household of segment h will choose zone i, mode m, and dwelling k, as

$$P^h_{imk} = \text{Prob}\,[\hat{U}^h_{imk} > \hat{U}^h_{jnp}, \forall\,(j,n,p) \neq (i,m,k)]. \tag{2}$$

Because of the separability of utility, the assumption that the random terms ε^h_{imk} are distributed according to the generalized extreme value distribution implies that the following logistic model is consistent with utility maximization:

$$P^h_{imk} = P^h_i\, P^h_{m/i}\, P^h_{k/im}\ , \tag{3}$$

where

$$P^h_{k/im} = \frac{\exp\,[U^h_{imk}/(1-\delta^h)]}{\sum_{s=1}^{S_i} \exp\,[U^h_{ims}/(1-\delta^h)]}, \quad k = 1, \ldots, S_i, \text{ each } (i,m), \tag{4}$$

$$P^h_{m/i} = \frac{\exp\,\{[U^h_{im} + (1-\delta^h)K^h_{im}]/(1-\sigma^h)\}}{\sum_{n=1}^{M^h_i} \exp\,\{[U^h_{in} + (1-\delta^h)K^h_{in}]/(1-\sigma^h)\}}, \quad m = 1, \ldots, M^h_i, \text{ each } i \text{ with} \tag{5}$$

$$K^h_{in} = \log \sum_{s=1}^{S_i} \exp \frac{U^h_{ins}}{1-\delta^h} \tag{6}$$

and

$$P^h_i = \frac{\exp\,\{U^h_i + [(1-\delta^h)/(1-\sigma^h)]J^h_i\}}{\sum_{j=1}^{I} \exp\,\{U^h_j + [(1-\delta^h)/(1-\sigma^h)]J^h_j\}}, \quad i = 1, \ldots, I, \tag{7}$$

with

$$J^h_j = \log \sum_{m=1}^{M^h_j} \exp \frac{U^h_{jm} + (1-\delta^h)\,K^h_{jm}}{1-\sigma^h}.$$

This is the nested logit model developed by McFadden (1978) with two levels of nesting: The choice of dwelling is conditional on the choice of zone and mode, and the choice of mode is conditioned on the choice of zone. The empirical coefficient δ^h is an average measure of the similarity or correlation of the random utility terms for dwellings given zone and mode, and σ^h is an average measure of the similarity or correlation of the random utility terms for travel modes given zone and dwelling. McFadden (1978) has noted that for the model to be consistent with utility maximization, the empirical coefficients δ^h and σ^h should obey $0 \leq \delta^h \leq \sigma^h < 1$ when estimated simultaneously with the preference coefficients in U^h_{imk}, U^h_{im}, and U^h_i.

The supply-side problem is one of landlords' profit maximization: Each landlord must choose whether to rent the dwelling or whether to keep it vacant. Suppose that the perceived profit function for the landlord of dwelling k in zone i is

$$\hat{\Pi}_n^{ik} = \Pi_n^{ik} + \xi_n^{ik}, \qquad n = 1, 2, \tag{8}$$

where n = 1 is the "keep vacant" alternative and n = 2 is the "offer for rent" alternative; Π_n^{ik} is the part of profit which is a function of observable attributes, and ξ_n^{ik} is the part of profit which is a function of unobserved (random) attributes. Then if ξ_1^{ik} and ξ_2^{ik} are independently and identically distributed according to the extreme value distribution, profit maximization

$$Q^{ik} = \text{Prob}\ (\hat{\Pi}_2^{ik} > \hat{\Pi}_1^{ik}) \tag{9}$$

yields the binary logit model

$$Q^{ik} = \exp\frac{\Pi_2^{ik}}{\exp \Pi_1^{ik} + \exp \Pi_2^{ik}}, \tag{10}$$

where Q^{ik} is the probability that dwelling k in zone i will be offered for rent.

A crucial point is the way in which dwelling rents enter the demand- and supply-side models. Letting R_{ik} denote the rent of dwelling k in zone i, we note that this attribute should enter U_{imk}^h in the utility function. The profit functions can be expressed as

$$\Pi_2^{ik} = \lambda R_{ik} - \lambda C_2^{ik}, \tag{11}$$

$$\Pi_1^{ik} = -\lambda C_1^{ik}, \tag{12}$$

where λ is a scaling factor; C_2^{ik} is the observed cost to the landlord of maintaining an occupied dwelling; and C_1^{ik} is the observed cost to the landlord of maintaining a vacant dwelling.

Now suppose that the utility function depends on X_{ikv}^h, $v = 1, \ldots, V$, attributes which vary by zone and dwelling and X_{imkw}^h, $w = 1, \ldots, W$, attributes which vary by zone, mode, and dwelling. Let the zonal means of these attributes be X_{iv}^h and X_{imw}^h. Three parts of strict utility can now be written as

$$U_i^h = \sum_{v=1}^{V} \delta_v^h \{X_{iv}^h \quad \textit{or} \quad \log X_{iv}^h\}, \tag{13}$$

$$U_{im}^h = \sum_{w=1}^{W} \beta_w^h \{X_{imw}^h \quad \textit{or} \quad \log X_{imw}^h\}, \tag{14}$$

$$\begin{aligned} U_{imk}^h = {} & \sum_{v=1}^{V} \delta_v^h \{e_{ikv}^h \quad \textit{or} \quad \log d_{ikv}^h\}, \\ & + \sum_{w=1}^{W} \beta_w^h \{e_{imkw}^h \quad \textit{or} \quad \log d_{imkw}^h\}. \end{aligned} \tag{15}$$

The zone average of each attribute is allowed to enter U_i^h or U_{im}^h either linearly or loglinearly. If the attribute enters linearly, then that attribute's additive deviation from the mean for dwelling k (e_{ikv}^h or e_{imkw}^h) enters U_{imk}^h linearly. If the attribute enters loglinearly, then the log of that attribute's multiplicative deviation from the mean for dwelling k (d_{ikv}^h or d_{imkw}^h) enters U_{imk}^h loglinearly. To give an example of this, we will consider the attribute $R_{ik} + C_{imk}^h$, where R_{ik} is the rent for dwelling k in zone i and C_{imk}^h is the commuting cost for a type h household choosing (i,m,k). This attribute can be entered in loglinear form so that log $(R_i + C_{im}^h)$ enters U_{im}^h and log d_{imk}^h enters U_{imk}^h, where $d_{imk}^h = (R_{ik} + C_{imk}^h)/(R_i + C_{im}^h)$ and where R_i is the zone average rent and C_{im}^h is the zone average travel cost for mode m and segment h households. This specification of utility will be employed in the empirical application of the model.

III. EXISTENCE, UNIQUENESS, AND STABILITY OF DWELLING AND SUBMARKET EQUILIBRIA

Equilibrium will be defined at two levels of resolution. At the disaggregate level an equilibrium is a state in which the expected value of the demand for a dwelling equals the expected value of the supply of that dwelling by the landlord. At the level of zones (or submarkets) an equilibrium is a state in which the expected value of the demand for a zone equals the expected value of the number of dwellings supplied in that zone. For a disaggregate equilibrium to be maintained dwelling rents and therefore demand and supply probabilities must adjust.

The conditions for a *dwelling equilibrium* to hold are

$$\sum_h N^h P_i^h \sum_m P_{m/i}^h P_{k/im}^h = Q^{ik}, \qquad \text{each } (i,k), \tag{16}$$

which is a system of $\sum_{i=1}^{I} S_i$ equations in the same number of unknowns R_{ik}.

The conditions for a *submarket equilibrium* to hold are

$$\sum_h N^h P_i^h \sum_m P_{m/i}^h \sum_k P_{k/im}^h = \sum_k Q^{ik}, \tag{17}$$

or, more simply,

$$\sum_h N^h P_i^h = \sum_k Q^{ik}, \qquad \text{each } i, \tag{18}$$

which is a system of I equations in the I unknowns R_i [the average zone rents, given *fixed* values for the inclusive values K_{jn}^h for each (j,n) and given a fixed distribution of rents for dwellings within a zone relative to the mean rent of that zone].

One example of assumptions that are consistent with the above definition of equilibrium are as follows. Suppose that the rent of dwelling k in zone j is $R_{jk} = R_j + r_{jk}$, where R_j is the mean rent of the zone and r_{jk} is the deviation of the rent of the kth dwelling from the zone mean such that $\sum_{k=1}^{S_j} r_{jk} = 0$. This assumption allows us to write

$$\Pi_2^{ik} - \Pi_1^{ik} = \lambda R_i - \lambda(C_2^{ik} - C_1^{ik}) + \lambda r_{ik}. \tag{19}$$

Furthermore, if rent enters strict utility linearly, we can write $U_i^h = \alpha_R^h R_i + U_i^{h'}$, where $\alpha_R < 0$ is the rent coefficient and $U_i^{h'}$ is the remaining part of zone specific utility, and we can also write $U_{imk}^h = \alpha_R^h r_{ik} + U_{imk}^{h'}$, where $U_{imk}^{h'}$ is the remaining part of (i,m,k)—specific utility. Then, the inclusive values K_{im}^h are

$$K_{im}^h = \log \sum_{k=1}^{S_i} \exp \frac{\alpha_R^h r_{ik} + U_{imk}^{h'}}{1 - \delta^h}. \tag{20}$$

Now given fixed values r_{ik} for each (i,k), one can precompute each K_{im}^h and also each λr_{ik}. One can then enter (18) with these fixed values and solve for each mean zone rent R_i. The linear specification of rent in the utility function is not always empirically satisfactory, and loglinear specifications do not allow the above additive separability of dwelling and submarket rent.

When one observes only the mean submarket rent and mean submarket attributes without observing the dwelling rents within the submarket, then a cruder model is necessary. When this is the case the term λr_{jk} can be included in the random profit terms ξ^{jk}, thus reflecting some aggregation error. Equation (10) then becomes

$$Q^i = \frac{\exp \Pi_2^i}{\exp \Pi_1^i + \exp \Pi_2^i}, \tag{21}$$

where Q^i is the probability that a random dwelling in submarket i will be offered for rent and $\Pi_1^i = -\lambda C_1^i$, $\Pi_2^i = \lambda R_i - \lambda C_2^i$. On the demand side the attribute containing the mean submarket rent is included in U_i or U_{im}, and the part containing any deviation from the mean rent is included in the random part ε_{imk}. Thus, the demand model will also reflect some aggregation error which implies $P_{k/im} = 1/S_i$. The equilibrium conditions (18) for such an aggregated model can be written as

$$\sum_h N^h P_i^h(\bar{R}) = S_i Q^i(R_i), \qquad \text{each } i, \tag{22}$$

where P_i^h is the submarket choice probability with aggregation error and $\bar{R} = [R_1, R_2, \ldots, R_I]$ is the vector of mean submarket rents.

To examine the existence and uniqueness of an equilibrium satisfying (22), we first define an equilibrium more precisely.

Definition: A mean submarket rent vector $\bar{R}^* = [R_1^* \, R_2^* \cdots R_I^*]$ is an equilibrium vector if it satisfies the conditions

$$\left.\begin{aligned} &\mathscr{E}_i(\bar{R}^*) = \sum_h N^h P_i^h(\bar{R}^*) - S_i Q^i(R_i^*) = 0 \\ &\text{and} \quad R_i^* - \theta_i^2 = 0 \qquad \text{for each } i, \end{aligned}\right\} \tag{23}$$

where $\mathscr{E}_i(\bar{R}^*)$ is the excess demand function for submarket i and θ_i^2 is a nonnegative slack variable.

The system (23) contains 2I unknowns in 2I equations and rules out negative rents. The Jacobian matrix of (23) is

$$\mathscr{J} = \left[\begin{array}{ccc|cccc} & \dfrac{\partial \mathscr{E}_i}{\partial R_j} & & & & \bar{0} & \\ \hline 1 & & 0 & -2\theta_1 & & & 0 \\ & \ddots & & & -2\theta_2 & & \\ 0 & & 1 & 0 & & & -2\theta_I \end{array}\right],$$

where

$$\frac{\partial \mathscr{E}_i}{\partial R_j} = -\sum_h \frac{N^h}{1-\delta^h} P_j^h P_i^h \sum_{m=1}^{M_j^h} P_{m/j}^h \left(\frac{\partial U_{jm}^h}{\partial R_j} \right) > 0 \qquad \text{for } j \neq i \tag{25}$$

and

$$\frac{\partial \mathscr{E}_i}{\partial R_i} = \sum_h \frac{N^h}{1-\delta^h} P_i^h(1-P_i^h) \sum_{m=1}^{M_i^h} P_{m/i}^h \left(\frac{\partial U_{im}^h}{\partial R_i} \right) - \lambda S_i Q^i(1-Q^i) < 0 \qquad \text{for } j = i. \tag{26}$$

The above signs follow from $\partial U_{jm}^h / \partial R_j < 0$.

A globally unique (and stable) equilibrium satisfying (23) occurs if the Jacobian matrix $\mathscr{J}$ is such that $(-1)^{2I}|\mathscr{J}| > 0$. This condition will be satisfied if $\mathscr{J}$ or its transpose $\mathscr{J}'$ has a negative dominant diagonal (recall $|\mathscr{J}| = |\mathscr{J}'|$). That the diagonal is negative is seen from (26). For the diagonal of the transpose to be dominant, we require that $D_i = |A_{ii}| - \sum_{j \neq i} |A_{ji}| > 0$, where A_{ji} is the (j, i)th element of the Jacobian. From (25) and (26) we find that

$$D_i = \lambda S_i Q^i(1-Q^i) - 1. \tag{27}$$

Condition (27) may appear restrictive, but a stronger result is obtained if we assume that all rents R_i^* will be positive ($R_i^* > 0$ for each i) at equilibrium. In this case the nonnegativity conditions for R_i^* can be ignored and we can prove that equilibrium is unique and stable in any arbitrarily large neighborhood which does not include $R_i^* = 0$ for any i. To prove this, we examine the dominance of the transpose and find it to be

$$D_i = \lambda S_i Q^i(1-Q^i) > 0 \qquad \text{for each } i. \tag{28}$$

From these observations we can conclude that if a vector $\bar{R}^*$ is a unique equilibrium solution to (23) and this vector contains elements all of which are substantially greater than zero, then shifts in the demand and supply equations will result in another unique equilibrium as long as these shifts are not large enough to require that $R_i^* = 0$ for at least one i.

A rapidly convergent Newton–Raphson type algorithm is used to solve for the new unique equilibrium. In the empirical application to be described in the next two sections this algorithm is used to solve 1690 equations simultaneously.

IV. THE EMPIRICAL MODEL AND ITS ESTIMATION

To estimate an empirically workable model consistent with the previous section's developments, we use the 1970 housing and transportation census data for the Chicago SMSA tabulated by $\frac{1}{2}$ mile by $\frac{1}{2}$ mile small zones. This data tabulates the travel mode and residential location choices of commuters by their workplace for each $\frac{1}{2}$ mile by $\frac{1}{2}$ mile residential zone. The Chicago SMSA is divided into a grid of 4918 such zones. Three thousand and seventy-three of these zones report some work trips to the 2 mile by 2 mile Chicago CBD which contains 19 percent of the metropolitan jobs with the remaining 81 percent thinly distributed throughout the SMSA. Since our objective is to test CBD-oriented transportation policies, we emphasize the estimation of a CBD demand model and also estimate an aggregated demand model which represents the choices of non-CBD commuters grouped across all non-CBD workplaces. Finally, the demands of some CBD and non-CBD commuters using certain unusual or minor modes such as walking, bicycling, or taxi are treated as fixed. The excess demand function for the number of occupied dwellings in each zone i can be written as

$$\mathscr{E}_i(\bar{R}) = \left[N^c \sum_{m=1}^{M_i^c} P_{im}^c(\bar{R}) + N^{\not c} \sum_{m=1}^{M_i^{\not c}} P_{im}^{\not c}(\bar{R}) + N_i^F \right] \delta_i - S_i Q_i(R_i), \quad (29)$$

where $\bar{R}$ is the vector of zonal average rents; N^c and $N^{\not c}$ are the given numbers of CBD and non-CBD commuters, respectively, whose choices are explained; N_i^F is the number of commuters choosing zone i whose choices are taken as fixed, and δ_i is the ratio of households to commuters residing in zone i; M_i^c and $M_i^{\not c}$ are the number of commuting modes available to CBD and non-CBD commuters residing in zone i; P_{im}^c and $P_{im}^{\not c}$ are the probabilities that a randomly selected CBD and non-CBD commuter will choose residential zone i and travel mode m given the workplace location and the average values of utility attributes for that zone; S_i is the number of dwellings in zone i; and Q_i is the probability that a randomly selected dwelling in zone i will be offered for rent by the landlord of that dwelling.

The choice probabilities are given as

$$P_{im} = P_i P_{m/i}, \tag{30}$$

where

$$P_i = \frac{S_i \exp[U_i + (1-\sigma)I_i]}{\sum_j S_j \exp[U_j + (1-\sigma)I_j]} \tag{31}$$

$$I_j = \log \sum_{m=1}^{M_j} \exp \frac{U_{jm}}{1-\sigma} \tag{32}$$

$$P_{m|i} = \frac{\exp[U_{im}/(1-\sigma)]}{\sum_{n=1}^{M_i} \exp[U_{in}/(1-\sigma)]}, \tag{33}$$

which is a special case of (5) to (7) with $\delta = 0$. In addition, we assume that zone attributes enter U_i linearly or loglinearly as in (13) with the δ coefficients to be estimated. Zone and mode specific attributes enter U_{im} linearly or loglinearly, and the coefficients $\beta/(1-\sigma)$ are to be estimated with $1-\sigma$ to be estimated as the inclusive value coefficient.

The estimation results are obtained by first maximizing the conditional log-likelihood

$$\log \mathcal{L} = \sum_{i,m} \mathring{N}_{im} \log P_{m/i}\left(\frac{\bar{\beta}}{1-\sigma}\right), \tag{34}$$

where $\mathring{N}_{im}$ is the number of commuters in the estimation sample observed to choose (i,m). Next, one estimates $\bar{\alpha}$ and $1-\sigma$ given the estimate of $\bar{\beta}/(1-\sigma)$ by maximizing the marginal log-likelihood

$$\log \mathcal{L} = \sum_i \mathring{N}_i \log P_i(\bar{\alpha}, 1-\sigma), \tag{35}$$

where $\mathring{N}_i$ is the number of commuters in the estimation sample observed to choose zone i.

It follows from McFadden (1978) that the above sequential estimation based on a random sample of zones yields consistent and efficient estimates of the utility coefficients as long as the specified model is accurate. Since the data is aggregated, the estimated coefficients will include some aggregation errors.

The estimation results shown in Table 1 are obtained from a sample of randomly selected 433 zones. The coefficients of attributes 1 to 10 are in the conditional part of the model, and those of 11 to 20 in the marginal part.

Attributes 1 to 3 are the traditional mode dummies. The CBD model has up to four modes available in a zone: auto, bus, commuter rail, transit (subway or elevated). The non-CBD model has auto and bus. Six percent of CBD and 15 percent of non-CBD trips comprise all other modes of travel

Table 1. Estimated Choice Model Coefficients (t scores in parentheses)*

Utility Attributes	CBD (c)		Non-CBD (¢)	
1. Computer rail (CR) dummy	−0.845	(23.0)	—	
2. Rapid transit (RT) dummy	−1.701	(39.0)	—	
3. Bus dummy	−0.636	(12.3)	−2.627	(175.0)
4. log (travel time)	−2.392	(55.5)	−0.910	(25.7)
5. log (travel cost + rent)	−1.488	(12.4)	−5.461	(42.6)
6. Bus miles/square mile	0.020	(54.4)	0.017	(70.5)
7. Number of RT stations (0–$\frac{1}{2}$ mile)	0.294	(20.9)	—	
8. Number of RT stations ($\frac{1}{2}$–1 mile)	0.134	(9.9)	—	
9. Number of RT stations (1–2 mile)	0.246	(23.2)	—	
10. Number of CR stations (0–1 mile)	0.349	(19.9)	—	
11. log (Housing age)	−0.188	(14.0)	−0.097	(14.5)
12. log (Income)	1.015	(53.2)	−0.117	(8.4)
13. log (Distance)	0.447	(18.4)	0.426	(47.9)
14. log (Angle)	—		−0.006	(23.0)
15. D1 (0–10 miles)	0.490	(19.6)	0.287	(20.2)
16. D2 (10–20 miles)	0.122	(6.0)	0.296	(29.9)
17. D3 (> 25 miles)	−0.591	(20.6)	0.132	(12.3)
18. log (rooms)	—		1.194	(62.0)
19. Inclusive value	0.277	(30.7)	0.045	(15.3)
20. log (supply)	1.000	(—)	1.000	(—)
[log $\mathcal{L}^*$ − log $\mathcal{L}^0$]	16,508		121,129	
ρ^2	0.420		0.828	

Note:
* The large t scores are due to the large number of trips used to estimate these models. Roughly comparable t-score values would be obtained if disaggregate information for the same number of trips is used.

to work, and these are treated as fixed for each zone i by inclusion in N_i^F. Travel time or cost is measured as the average travel time or cost of CBD and non-CBD commuters residing in zone i. The zone average rent R_i is the sum of the average annual rent of renter-occupied units plus one-tenth the average value of owner occupied units. The "bus miles/square mile" of a zone is a measure of the density of bus service within that zone, and attributes 7 to 10 measure proximity to rail transit by counting the number of stations within certain distance intervals from the zone's centroid. Attribute 11 is the zone average housing age. Attribute 12 is the average income of a zone's residents as a measure of the zone's prestige or social status. Attribute 13 is the zone's airline distance from the CBD and 14 is the zone's counterclockwise displacement in degrees from the North Shore suburbs. Here D1, D2, and D3 are dummy variables representing distance intervals which roughly correspond to the city of Chicago, the inner suburbs, the outer suburbs, and the exurban areas. Taken together, attributes 13 to

17 proxy the complex location effects which determine a zone's attractiveness within the SMSA. Finally, attribute 18 is the zone average number of rooms in that zone's housing units. Table 1 reports what I consider the most successful estimations of the CBD and non-CBD models. The t statistics (in parentheses) are high because of the large number of commuters (observations) used to estimate the models. Nearly all attributes have correct signs, reasonable magnitudes, and are significant.

The coefficients of the supply-side model are similarly estimated via maximum likelihood and are shown in Table 2. Attributes 3 to 5 which measure the percent of a zone which is occupied by black households, the percent which is developed, and the percent which is single-family housing, together with housing age and the attribute "angle" proxy the effect of $-\lambda(C_2 - C_1)$, i.e., the differential average cost of maintaining an occupied vs. a vacant dwelling in that zone.

The travel cost, travel time, and rent elasticities of demand for the CBD and non-CBD models are reported in Table 3. These have been calculated from the 433-zone estimation sample and are in general agreement with similar elasticities computed from models estimated by others and recently surveyed by Gomez-Ibanez and Fauth (1980).

Once the coefficients of the utility function are estimated, the choice models can be used to make predictions for an appropriately defined simulation zone system. The 4918 zones of the SMSA are aggregated into 1690 simulation zones. Seven hundred and sixty-three of these are $\frac{1}{2}$ mile by $\frac{1}{2}$ mile zones within the city of Chicago, and the remaining 927 are 1 mile by 1 mile or larger suburban zones. All the model attributes are recomputed for the simulation zone system.

The estimated CBD, non-CBD, and supply-side choice models can be adjusted to the simulation zone system by incrementing each zone and

Table 2. Estimated Coefficients of the Supply-Side Model (t scores in parentheses)

Profitability Attributes	
1. Dummy	−0.679 (17.2)
2. Rent (λ)	0.00013 (19.5)
3. Percent black	−0.347 (32.2)
4. Percent developed	1.084 (55.2)
5. Percent single family	1.718 (109.4)
6. log (Housing Age)	0.471 (48.1)
7. Angle/100	0.075 (11.1)
$2[\log \mathcal{L}^* - \log \mathcal{L}^0]$	2,268,000
ρ^2	0.740

Table 3. Elasticities of Estimated Models

Attribute	Demand Model CBD	Non-CBD
Rent	−0.314*	−0.205
Travel cost	−0.246	−0.256
Travel time	−1.694	−0.251

Note:
* Elasticity: average percent change in the expected number of commuters choosing a zone for a 1 percent increase in the attribute.

mode specific strict utility U_{im} by D_{im}, where the latter is an alternative specific dummy which measures the effect of missing attributes in the strict utility. The values of these D_{im}'s can be adjusted so that predicted and observed trips are equal for each (i,m) in the 1690-zone simulation data. A similar adjustment is also performed to the supply-side model so that the predicted and observed vacancies are equal for each zone. These adjustments clear the model from any prediction errors and complete the task of model calibration.

V. POLICY ANALYSIS

Three proposed rail transit projects radially connecting the inner suburbs of the southwest side of Chicago (see Figure 1) to the CBD are selected for policy analysis. These projects are the Archer avenue subway, the Gulf Mobile & Ohio (GM&O) at-grade project, and the Indiana Harbor Belt (IHB) elevated/at-grade/subway project. These projects would cost $497.9 million, $254.3 million, and $511.4 million, respectively. In order to test the effect of each project on equilibrium housing rents, we first use a transit access model developed and estimated for Chicago by Sajovec and Tahir (1976). This model enables us to estimate the average cost of access and travel time of access from each zone in the southwest corridor to each station of each project. These access costs and times are combined with the station-to-CBD times of each station to estimate the average time and cost of traveling from each zone in the southwest corridor to the CBD. Non-CBD travel times and costs are scarcely affected by these radial projects and are assumed to remain unchanged for simplicity. Eighty-nine of the 205 zones within the southwest corridor do not report any rapid transit trips in 1970. However, since each of these zones comes within close proximity of the proposed projects, each is a potential transit ridership zone once one of

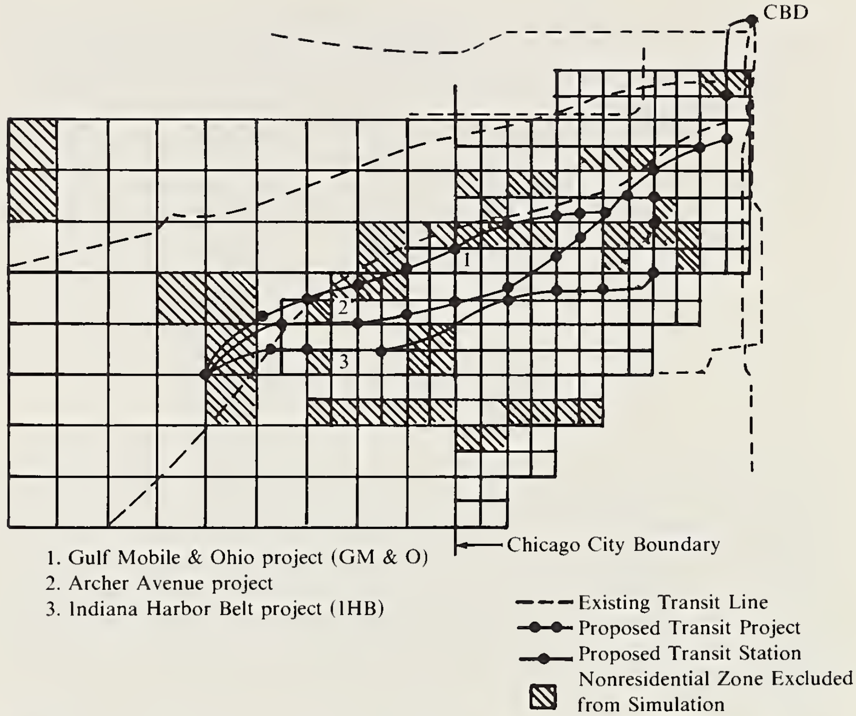

Figure 1. Alignment and station locations of the Archer, IHB, and GM&O proposed rapid transit projects within the Southwest corridor.

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the projects is built. Thus one must estimate the value of the rapid transit specific constant (dummy variable) for each of these zones. To do so, we use the remaining 116 zones within the corridor which report both auto and transit trips in 1970 and thus have both auto and transit specific constants (D_{ia} and D_{it}) and estimate the regression

$$D_{it} = -0.344 - 0.823\, D_{ia}, \qquad R^2 = 0.488.$$

$$(0.094)(\ 0.079)$$

The numbers in parentheses are the standard errors of the regression constant and its slope coefficient. This estimated regression is used to predict the unobserved values of the transit constant D_{it} from the observed values of the auto constant D_{ia} for those 89 zones which report auto trips but no transit trips. These predicted values of the D_{it}'s are then entered into the CBD utility functions. Through this adjustment the equilibrium model is able to generate rapid transit trips from those zones which in the initial 1970 situation do not report any transit trips.

The access times and costs together with the locations of the rapid transit stations and the rapid transit specific constants are used to update the demand-model attributes of Table 1. Changes in these attributes disturb the initial equilibrium, and the Newton-Raphson type algorithm is used to find the new equilibrium rent vector $\bar{R} = [R_1 \, R_2 \cdots R_I]$ as the unique solution of the 1690 zone (equation) system. Model choices for CBD and non-CBD employees, zone occupancy, and vacancy levels are then computed from the equilibrium rent vector. This policy simulation procedure is applied to each of the Archer, GM&O, and IHB projects shown in Figure 1. An estimate of the total daily ridership on each line is obtained by multiplying the one-way CBD trips by 4 (a valid rule of thumb for the Chicago area). From ths figure and other service characteristics the annual operating cost and feeder bus operating cost of each project is computed using standard procedures for the Chicago area (see Krueger et al., 1980; Chicago Transit Authority, 1980). Major results for each of the three projects are summarized in Table 4. Figure 2 shows the equilibrium annual rent level and change in annual rent caused by the GM&O project in each of the zones in the southwest corridor. It is seen that the maximum annual rent increase is $247, or $21 per month. Zones with the largest increases are generally located adjacent to the proposed transit stations. As one moves away from these stations one generally encounters smaller increases, and substantially far-away rents will decrease, but the maximum decrease in Figure 2 is only $6 annually, an insignificant amount. As one would expect, outside the corridor rent decreases are even smaller. The predicted magnitudes of these rent changes have very encouraging policy implications. First, if a value capture policy is to be implemented, then the annualized lump sum tax to be paid by the average property owner is not large. Second, where rents decrease, the change is so small as to be negligible: rebates may be safely avoided. What remains to be examined is whether a value capture policy would succeed in raising a large part of the total cost of the rail investment. The answer is in Table 4 which shows that value capture would raise from 13.9 to 17.8 percent of the total cost of the three projects and that value capture plus normal fare revenues would raise from 18.1 to 23.2 percent of the total cost. These figures are encouraging if we recall that they are merely probable lower bounds. If we include the effects of value capture on commercial floor space and vacant land, if we optimize the boundary of the corridor (special assessment district), and if we include the possibility of some land development around transit stations, then we can expect much higher recovery ratios. Finally, if appropriate gasoline taxes, rush hour parking taxes, and appropriate fare increases are also implemented, then the financing of mass transit systems to a substantial

Table 4. Major Policy Results for the Three Simulations: *Changes Within the Southwest Corridor Area*

	Rent Change (%)			Mode Demand Change (%)						Employee Change[a]	
				CBD				Non-CBD			
Project	City	Suburb	Total	Auto	Rail	Transit	Bus	Auto	Bus	CBD	Non-CBD
Archer	2.92	0.70	1.89	−6.45	−2.07	78.31	−8.5	0.33	−3.13	657	−634
IHB	2.73	0.73	1.80	−6.23	−1.91	73.79	−7.8	0.31	−2.96	622	−601
GM&O	2.14	0.72	1.48	−5.21	−2.12	62.45	−6.6	0.31	−2.66	516	−499

Project	New Passengers (one-way CBD work trips)	Annual Operating Cost (1000 $)	Annual Capital & Operating Cost (1000 $)	Annual Value Captured[b] (1000 $)	Annual Fare Revenue (1000 $)	Annual Fare Revenue to Operating Cost Ratio	Annual Value Captured to total Cost Ratio	Annual Value Captured Fare plus Revenue to Total Cost Ratio
Archer	3832	9,993.2	54,453.3	8,211.0	2,440.4	0.244	0.151	0.196
IHB	3611	10,371.0	55,831.3	7,810.0	2,299.6	0.222	0.139	0.181
GM&O	3057	9,828.9	36,212.9	6,446.0	1,946.8	0.198	0.178	0.232

Notes:

[a] Number of employees who relocate into or move out of the Southwest Corridor Study Area.

[b] Value captured: net revenues generated by a lump sum incremental tax and rebate scheme applied to housing within the corridor.

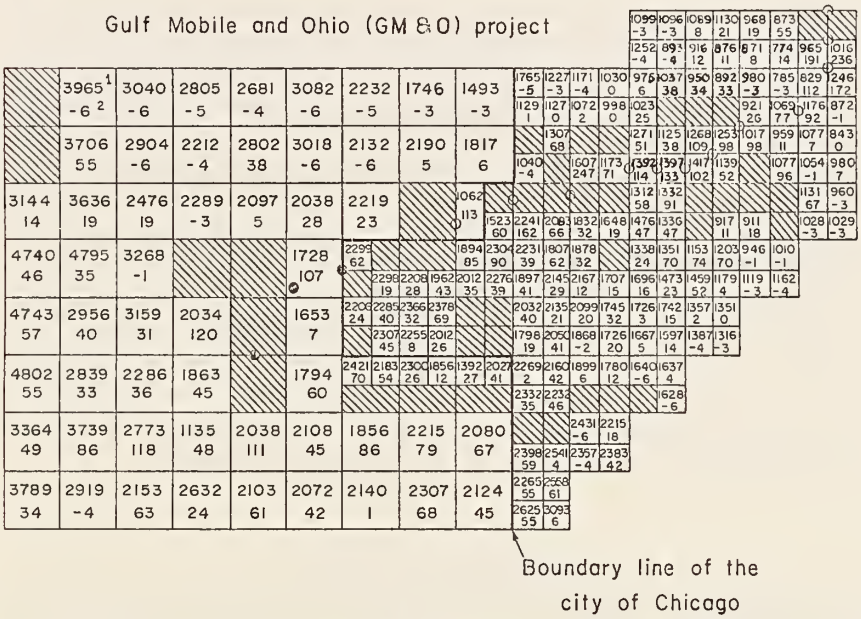

Figure 2. New equilibrium zone rents and rent changes for the GM&O project.

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degree, via local means, becomes a real possibility in the 1980s. Even though the suburbanization of population and employment between 1970 and 1980 has somewhat weakened the value capture potential of mass transit, our simulations, with a roughly updated 1970 data set, show that housing value capture which raised 17.8 percent of the total cost of the GM&O project in 1970 can still raise at least 9.7 percent of the total cost in 1980. In all these calculations we used an interest rate of 15%. Reducing this interest rate to 10% substantially improves the percentage of cost recovered up to 36% for the GM&O project.

This paper has demonstrated that equilibrium models based on stochastic choice formulations can be fruitfully used to analyze questions of policy importance. Conclusions reached with such equilibrium simulations can differ greatly from conjectures established from crude observations of elasticity measures alone. Ultimately, fundamental questions about the potential of value capture policy cannot be fully answered with hedonic regression techniques which estimate housing prices as a function of transit system characteristics (see Dewees, 1976; Lerman et al., 1977). Thus, this study complements these previous studies which have demonstrated that transit has a statistically significant impact on property values without deriving full metropolitan equilibrium estimates of these impacts.

Finally, the equilibration framework utilized in this study points the way for the integration of urban economics, and the theory of land rent in particular, with mode choice analysis in transportation planning. However, the discrete choice methodology developed and tested in this paper need not be confined to transportation systems alone. Other public investments such as water supply and distribution systems and sewage collection and treatment systems can also be examined using the same techniques. The presence and characteristics of these investments influence the locational choices of households and the decisions of landlords and developers to determine the use of land or buildings. Thus, appropriate respecification of demand and supply equations and reestimation of these equations in various contexts greatly generalizes the techniques which in this paper have been demonstrated for the case of transportation investment.

ACKNOWLEDGMENT

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16. Abstract

The study develops a model for use in forecasting the impacts of multi-modal urban transportation improvements. The model, named the Chicago Area Transportation-Land Use Analysis System (CATLAS), is a dynamic methodology developed to forecast and analyze the following types of effects from transportation investments: changes in modal splits, changes in vacancy rates, housing and land values, changes in housing stock, changes in consumer and producer surplus and changes in tax bases. The forecasts are determined annually and by small geographic zones in a metropolitan area. Transportation improvements and investments are represented by changes in zone to zone travel times and costs. A central focus of CATLAS is the evaluation of value capture policy by examining the pecuniary impact of transportation on housing and land values. These benefits may be captured by a special assessment tax and are important in determining benefit-cost calculations.

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METRIC CONVERSION FACTORS

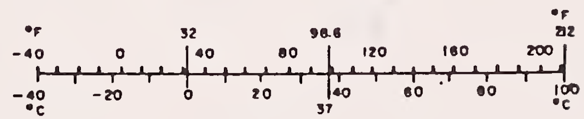
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



THE CHICAGO AREA TRANSPORTATION - LAND USE ANALYSIS SYSTEM*

A Dynamic Methodology for Forecasting the Impact of Multimodal Metropolitan Transportation Changes on Travel Mode Choices, Residential Location, Housing Stock Adjustment, Housing Values and Value Capture Potential.

By

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April 1983

*Final Report of "The Effects of Transportation on the Tax Base and Development of Cities," Contract DOT-RC-92028, University Research Program of the United States Department of Transportation.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Chicago Area Transportation - Land Use Analysis System (CATLAS) is a dynamic methodology developed to forecast and analyze the impacts of multi-modal urban transportation improvements and investments on the following:

a. changes in modal splits in travel to work among competing modes such as auto, commuter rail, rapid transit and bus,

b. changes in housing vacancy rates,

c. changes in housing and land values,

d. changes in the housing stock (new dwellings constructed and old dwellings demolished),

e. changes in economic measures of benefit such as consumer surplus and producer surplus and changes in the tax bases of city and suburban areas.

The above forecasts are determined annually and by small geographic zones in a metropolitan area. Transportation improvements and investments are represented by changes in zone to zone travel times and costs computed from access decisions, station locations, fare structures and other transportation system data. A central focus of CATLAS is the evaluation of value capture policy by examining the pecuniary impact of transportation on housing and land values. These benefits may be capturable by a special assessment tax but must figure prominently in benefit-cost calculations even if they are not taxed. The Chicago application shows that under 1970 conditions, capitalized value changes are nearly 36-40% of the capital cost of rail rapid transit alternatives which have been proposed for Chicago's southwest side. Similar calculations for bus systems appear to be more promising.

CATLAS complements traditional transportation planning tools by making it possible to perform integrated benefit-cost analyses of transportation system changes. Such a capability is lacking in current transportation - land use packages which are not rooted in the principles of economic science.

The methodology of CATLAS is transferable to many metropolitan areas since the transportation system and the census of population and housing data utilized in CATLAS is commonly available where significant transportation planning agencies operate.

ACKNOWLEDGEMENTS

The research reported here was partially supported by research contract 92028 resulting from the United States Department of Transportation, University Research Program's funding year 1979 solicitation. The project was titled "The Effects of Transportation on the Tax Base and Development of Cities" and the research lasted from July 1979 to January 1983.

During these three and a half years I received encouragement and helpful comments from Robert Martin of USDOT, who was the project monitor.

Cheri Heramb and Christopher Krueger of the Department of Public Works of the City of Chicago; Don Kopec and Anant Vyas of the Chicago Area Transportation Study; and Ashish Sen and Siim Soot of the University of Illinois at Chicago Circle generously helped with data resources utilized in the study and commented on aspects of the study.

My graduate students Chaushie Chu and Liang Shyong Duann made major contributions to the project, undertaking detailed investigations of related topics in their PhD dissertations.

The final report which forms the basis of this publication was presented at the Department of Transportation in June 1983. Useful comments were contributed by Fred Ducca, Robert Martin, James Ryan and Edward Weiner during this review and presentation. Of course, the results and the opinions expressed herein are the author's responsibility and may not be shared by the Department of Transportation.

NOTE TO THE READER

This report provides a brief overview of CATLAS (The Chicago Area Transportation Land Use Analysis System). Although some technical detail is included, the discussion is focused on conceptual structure, the empirical results and the policy applications. Readers interested in more detail can find it by referring to the book by Anas (1982) and the PhD dissertation by Duann (1982).

1. INTRODUCTION AND SUMMARY

1.1 Policy Perspective and Background

The development of new highway systems in American cities in the postwar era has contributed to the waves of employment and population decentralization and to suburban sprawl. These changes in land use have increased the attractiveness and market prices of suburban real estate relative to central cities. Partly because of this, the tax bases of central cities have been gradually reduced, adding to the difficulties of maintaining the aging infrastructure systems.

A properly chosen transportation system improvement or new investment can help contain or minimize the adverse effects of a deteriorating central city economy or even make a contribution toward reversing the decline and creating economic opportunities in the central cities. To succeed in this way, transportation policy must be coordinated with land use regulations, with the creation of enterprise zones and with fiscal planning. If transportation systems must be trimmed and some disinvestment must take place, this must again be done in coordination with land use, employment and fiscal policies in order to minimize any adverse effects on the tax bases of central cities.

The worsening fiscal plight of many cities, the danger of future gasoline crises and the ongoing cutbacks in Federal subsidies are forcing central city governments to become increasingly sensitive to the fiscal implications of their investment-disinvestment options. Local initiative in transportation planning and especially in transit investment has received the endorsement of the Federal government.[1] During the Carter administration many cities--among them Buffalo, Houston, Pittsburgh, Honolulu and others--accelerated their plans to build new rail transit systems. Chicago has built the O'Hare extension and recently completed a Federally funded study of a fixed rail extension to be built in the southwest corridor.[2] The change in administration and the announcement of major cuts in Federal subsidies has not caused plans for rail systems to be shelved, but rather to be considered more carefully.[3]

It is well known that following a transportation improvement (or more generally any infrastructure investment), the prices of real estate near the improvement will increase due to the increase in accessibility and the quality of service and the decrease in travel time.[4] It has been argued that property taxes can be appropriately adjusted to tax away part or all of these increases.[5] This should be done by a legally permissible lump sum incremental tax levied as a one-time special assessment and to be paid by the current owner in annual increments and the balance in full upon resale of the property, rather than a change in tax rate. The tax revenues generated can be used to defray part of the capital cost of the transportation improvement. This concept is called "value capture". The government can further enhance the taxable portion of property values by speeding up or stimulating the development of real estate near the transportation system through zoning and other land use policies. This concept is called "joint development". The promise of value capture/joint development policy is that if it is successfully implemented it can help finance part of the cost of the new transportation system through local means, thus reducing the burden on the Federal government, which under the Carter administration was generally agreeable to subsidizing up to 90% of the cost of major improvements.

1.2 Development and Scope of CATLAS

There is a gap in our knowledge of how to estimate property value increases caused by a public investment. Urban economists have developed simplified mathematical models of long run equilibrium in the urban land and real estate markets. These models provide a sound theoretical basis for policy analysis but are not detailed enough for actual empirical application.[6] On the other hand, transportation planners place a strong emphasis on empirically estimable models, but these models focus only on the travel-related attributes and the demand for travel without properly taking into account the interactions between transportation, land use and property values through the markets for land and buildings.[7]

There is a need for a theoretically sound and empirically estimable dynamic model which can satisfy the transportation planner's travel demand forecasting requirements while at the same time predicting the operation of real estate markets and the adjustment in property values due to new or improved transportation systems.

The Chicago Area Transportation/Land Use Analysis System (CATLAS) is such a model which synthesizes our knowledge of "location rent analysis" from urban economics with our knowledge of "travel demand analysis" from transportation planning.[8] It is a dynamic model which simulates the market in recursive periods of one year in length, and for a geographic grid system of 1690 zones covering the Chicago metropolitan area. The distribution of jobs among the zones and the characteristics of the transportation system are assumed to be known in every year. CATLAS generates people's choices of travel mode (automobile, commuter rail, rail rapid transit, bus, and "other") and their choice of residential location. Transportation improvements or changes in parking fees, gas prices, transit fares, etc. change people's decisions of where they will live and how they will commute there, given where they work. This is a demand side process and it is assumed that people make their decisions rationally by choosing the most attractive (or utility maximizing) of the travel-location options available. Because people are different, their choices differ as well. On the supply side CATLAS simulates profit-maximizing behavior on the part of housing owners. Three decisions are simulated. For the owner of an existing dwelling unit the decision (which recurs every year) is whether to withdraw the dwelling from the market and keep it vacant or whether to supply it to the market by selling it or renting it out. The decision depends on the price or rent that the market will bear relative to the differential cost of maintaining the dwelling when it is occupied versus when it is vacant. Because owners evaluate these revenues and costs differently, some decide to withdraw their units while others will supply them. For the owner of vacant land, the decision is whether to build new housing on that land or whether to postpone that decision to the next year. If the landowner perceives that bigger profits can be made by building later, then the decision will be to postpone. Expectations of future profits will vary among landowners, and the current prices of dwellings and their occupancy status play an important role in estimating these expectations. The owner of an old dwelling or buildings faces a similar decision. If he perceives that demolishing the building and selling the land is more profitable than continuing to rent it out he will demolish and sell. Otherwise the decision will be postponed to the next year. Current occupancy and current rents are again crucial in how expectations are formed. Building new dwellings and demolishing old ones are major decisions that take time to implement. In CATLAS it is assumed that there is a one year lag: the number of new dwellings constructed and old ones demolished in a given year depend on decisions based on last year's conditions. The demand and supply side of a real estate market must be in some sort of balance. This balance comes about as prices and rents adjust in each geographic zone. If, for example, the demand for a zone's housing exceeds the supply, rents in that zone will increase in that year. This will favorably influence perceived profitabilities and, if vacant land is available, new housing will be built next year. In CATLAS it is assumed that the demand for occupancy in a zone in a given year equals the number of dwellings supplied for occupancy in that year. Prices and rents adjust within every year to make this possible. Such a clearing of the market is a "temporary equilibrium". Changes in outside influences such as travel characteristics or job locations will shift the system to a new "temporary equilibrium" next year.

As in any attempt to build a simulation model of the urban economy, numerous difficulties were encountered during the development of CATLAS. Many simplifying assumptions were made to sacrifice theoretical detail and empirical realism in order to achieve the most that was possible with the available data. Since CATLAS relies on the data regularly compiled by the decennial U.S. Census of population and housing, it can be easily transferred and adapted to any major metropolitan area where detailed information on transportation systems is available.

With better data and greater computing resources, CATLAS can be extended and refined to deal with different or more complex situations.[9] It is now being extended by including people's choices of shopping as well as housing location and also by including commercial and industrial land. It is expected that this extended version will be applied to Chicago and to Busan City, South Korea's second largest city, to compare the effects of transit investment on land use and real estate prices in these two cities. Another plan is to adapt CATLAS to Stockholm, Sweden, to study the efficiency of rent control and housing allowance policies in the low-income areas of that city. Finally, although CATLAS is designed to measure the effect of new or improved transportation systems on property values and land development, it can be adapted to measure the effects of any public infrastructure investment on property values.

A precise list of the simulation output of the current version of CATLAS is as follows:

(1) the average housing rent in each geographic zone in each year,

(2) the number of vacant dwellings in each geographic zone in each year,

(3) the number of commuters choosing each travel mode by geographic zone of residence and employment,

(4) the number of new dwellings built by zone in each year,

(5) the number of old dwellings demolished by zone in each year,

(6) the price of the vacant land in each zone in each year,

(7) the amount of vacant land in each zone in each year,

(8) the number of dwellings in each zone in each year,

(9) the change in aggregate housing and land rent (or producer surplus) by year and zone,

(10) the change in "consumer surplus" (a measure of benefits to households) by year and employment location.

The above can be computed for any change in the travel cost and travel-time structure of any of the transportation mode networks. The zonal results can be aggregated for the city of Chicago and the suburbs and for the city and suburban parts of the southwest corridor.

This report consists of five sections. The next section reviews briefly the literature relevant to the development of CATLAS. Section three presents and discusses the mathematical structure of CATLAS and the assumptions from which this structure is developed. Section four presents the empirical estimation results for each of the CATLAS submodels, and section five presents and discusses the results from the application of CATLAS to an analysis of the impact of three rapid rail projects that were proposed for Chicago's southwest corridor.

2. LITERATURE REVIEW

There are five lines of literature that are relevant to the subject matter of CATLAS. These are: (a) the theoretical literature on location and land use in urban economics; (b) empirical studies of the impact of transportation improvements on property values; (c) travel mode and location choice models, (d) economic urban simulation models and (e) noneconomic urban simulation models. The main developments and bibliographic references in each of these areas are briefly reviewed.

2.1 Theoretical Literature in Urban Economics

The theoretical literature has established a conceptual framework which facilitates the understanding of various influences on urban economic development. A large number of articles and books have been written and the level of sophistication of the literature has increased at a steady pace. Despite these advances, the crux of the theory remains essentially the same and has been developed in the earliest works of Mohring and Harwitz (1962), Alonso (1964), Mills (1967), Muth (1969), Beckmann (1969). The basic argument of this literature is that part of consumers' savings in travel cost (and travel time) are capitalized into land and property values. Although travel costs are explicitly treated in this literature, travel time savings are not considered explicitly, but it is understood that the same results apply to travel times as well. Extensions of the urban economist's models have been applied to the problem of land allocation to roads in the presence of congestion in traffic to confirm Vickrey's assertion (1965) that congestion tolls must be levied to achieve a socially optimal land-in-roads configuration. Well known in this area are the articles by Strotz (1965), Mills and Deferranti (1971), Solow and Vickrey (1971), Mills (1972) and Solow (1972). In all of these urban economic models the interest is in the relationship between uniform improvements in unit transportation costs and the aggregate value of land. Wheaton (1974) showed that an improvement in unit transportation costs in a city where all workers commute to the center, will increase the aggregate value of urban land while also improving the utility level or consumer surplus of the households as long as the city's total population remained unchanged by the transportation investment. Economists have been concerned with the question of whether changes in land values caused by a project are a reflection of the total benefits of that project. Addressing this question, Lind (1973) showed that in general the change in the value of land did not equal the total benefits, unless, due to special circumstances, land rents rise to eliminate all of the benefits or consumer surplus created by the project. Later, Pines and Weiss (1976) showed that utility benefits and land rent changes caused by a project can disagree even in sign. Arnott and Stiglitz (1981) reexamined the case of transportation improvements in a city where all workers commuted to the center and showed that while a transportation improvement decreased the travel cost per unit distance, the aggregate travel cost might increase, remain the same, or decrease, depending on the magnitude of the induced demand for land development caused by the cost improvement. They also showed that aggregate land rent may likewise rise, remain unchanged or fall. All of these theoretical analyses fail to separate travel time and travel cost improvements and deal only with hypothetical simple cases in which only uniform travel cost improvements occur. Even in such cases the relationship between aggregate rents and travel costs is complicated and does not yield any simple quantitative rules of thumb.

2.2 Empirical Studies of the Impact of Transportation Improvements on Property Values

In the empirical literature the focus is not on whether aggregate rent will increase or fall, or on how to measure benefits, but rather on how to measure the magnitude of changes in land or other real estate values following the transportation improvement. These studies generally agree that the improvement would increase values nearby.

The earlier studies are descriptive. They do not perform rigorous statistical analysis but rely on crude observation and monitoring in impact and control areas before and after transportation improvements. This method has been used to document the impacts of rapid transit (Spengler, 1930; Davis, 1965), expressways (Adkins, 1959; Lemly, 1959; Golden, 1968), interchange development (Ashley, 1965) and interstate highways (Wootan and Haning, 1960) on property values.

The more recent work uses statistical analysis. These can be grouped into: (a) those studies dealing with the impact of a major transportation facility prior to, during or shortly after its implementation, and (b) those focusing on the effects of facilities which have been in existence for some time. The best examples of the first kind are the study of the Lindenwold-Camden-Philadelphia line by Mudge (1972) and Boyce and Allen (1972), of a rapid transit line in Toronto by Dewees (1976) and of the Washington, D.C. METRO by Lerman et al., (1977). The findings of these studies hinge on the judicious application of multivariate regression analysis making substantial improvement on the descriptive studies. Although these studies claim to have established evidence of a positive effect on real estate prices, their findings include distortions due to the influence of transit on expectations and the observed effects may bear no relation to stabilized equilibrium prices. Less important are studies by Carroll et al., (1958),and Brigham (1964) who examined road and highway networks and Downing (1973) who examined bus routes. Some of these studies deal with facilities which have been in existence for some time.

A major shortcoming of all these studies is that they are exclusively focused on specific transportation facilities. Each tends to deal with a single or several selected facilities rather than attempt a region-wide or city-wide cross-sectional study of the effects of multimodal transportation systems. As a result, their findings are difficult to generalize and are biased by the peculiar conditions that may surround the studied facilities. The reason for this limitation is either a lack of city-wide data or the special interest in a specific facility, or both. All of these studies deal with price changes in statistical samples of real estate parcels and not with price changes in the aggregate.

2.3 Travel Mode and Location Choice Analysis

Since Warner's pioneering analysis of commuters' choices between auto and transit (1962), there has been a growing interest in forecasting how a population of commuters will be distributed among alternative travel modes. A related problem of how travelers choose trip destinations, and in particular their residential locations, has also received attention. The power of mode choice analyse has increased since the contributions of (McFadden (1973) and Domencich and McFadden (1975). Transportation planners can now analyze mode choices by drawing on the standard techniques of multinomial logit, nested logit and multinomial probit models. Logit and nested logit models have also been applied to the choice of residential location and the joint choice of travel mode and residential location. Articles reporting on such applications are by Anas (1975), Quigley (1976), Lerman (1977), McFadden (1978) and Anas (1981, 1982). In these studies housing rents enter the decision making process of households in their choice of residential location. The emphasis is on how to use the observed choices by households to estimate their preferences for location and travel. The resulting models predict choices of location and travel mode but not the aggregate behavior of housing prices in response to travel improvements. A purpose of CATLAS is to integrate the techniques of travel and location choice analysis into a framework for simulating aggregate adjustments in land and housing prices.

2.4 Economic Urban Simulation Models

The theoretical literature of urban economics has led to the development of large scale computational models intended for realistic policy application. These models simulate the clearing and equilibration of the market for land and buildings for a system of geographic zones. The earliest such model is the linear programming formulation of Herbert and Stevens (1960) who deal with the market allocation of housing to land and of households to housing. Linear programming is also used by Mills (1972) who examines the interdependent allocation of employment and housing in urban space. This model has been extended by Hartwick and Hartwick (1974) and by Kim (1979) who introduce more realism by dealing with the location of intermediate production industries and subway systems respectively. Mills's approach is intended to study the efficient allocation of land uses and as such it may not produce realistic predictions. Because of its stringent data requirements, it has not been possible to empirically apply either this model or one of its extensions.

There are two economic urban simulation models which have been empirically applied to policy questions concerning the housing market. These are the Urban Institute Model (UIM) (see de Leeuw and Struyk, 1975) and the National Bureau of Economic Research (NBER) model (see Ingram et al., 1972 and Kain et al., 1976). The former model treats the housing market in highly aggregated form and deals with ten-year changes in housing quality and household location within a metropolitan area. The building industry and government regulation are explicit in the model. The model is based on a well developed theory of housing market behavior and includes a number of innovative ideas. Weaknesses of the model are (1) its highly aggregated form which makes it inapplicable to situations requiring detail, (2) the fact that it can be statistically estimated only with rather crude aggregated data and (3) that the numerical algorithm it uses may not always be able to find a solution.

The NBER model is the most comprehensive urban simulation model developed. Unfortunately, it is not a very workable model because it cannot be consistently estimated since all of the data it requires is not available for the same metropolitan area. Some of its submodels are descriptive in nature and are not rooted in theory. The assignment of households to housing units follows a disequilibrium process rather than being rooted in well established market clearing procedures.

Both the UIM and NBER models have been applied to testing the effects of giving rent allowances to low income households. Although the models produce qualitative predictions expected from theory, the quantitative predictions may be less valid because of the data problems in estimating these models. Neither model has been applied to transportation policy analysis.

2.5 Noneconomic Urban Simulation Models

There is a number of urban simulation models developed to deal with questions of urban location and transportation/land use interactions, without drawing on the body of economic theory available to analyze these problems. These developments begin with Lowry's model (1964) and are extended in Goldner's Projective Land Use Model (PLUM) (1964) and more recently in Putman's Disaggregated Residential Allocation Model (DRAM) and Integrated Transportation Land Use Package (ITLUP) (1974). These models have an interesting approach to modeling the complex nonlinear interactions between employment, housing and transportation, but they do so without dealing with the economics that drive and underlie these processes. As a result, the models are physicalist in the sense that they can forecast population, employment and travel but without forecasting prices, rents, wages and other relevant economic variables. Ignoring these variables makes it difficult to interpret the forecasts and leads to inconsistent results. This family of models is unable to examine fiscal and financial impacts and to do cost benefit analysis of transportation projects in a way which takes into account their impacts on the land and housing markets.

2.6 How CATLAS Relates to the Literature

CATLAS is an economic urban simulation model primarily intended for testing the effects of transportation policies on housing and land values, on residential land development and on mode choice patterns. It can deal with any transportation policy which changes travel times and costs in any of several travel modes. CATLAS can be estimated in its entirety using widely available data and rigorous econometric procedures. CATLAS has well behaved solution properties and computes equilibrium allocations of households to dwellings.

CATLAS can be viewed as a synthesis of the land rent and land use models developed by urban economists following Alonso (1964) with the travel and location choice models developed by transportation planners following McFadden (1973). Thus, it is a tool for simultaneously doing travel demand and land rent analysis. Using CATLAS one can evaluate the direct benefits to the users of the transportation system, the indirect benefits to nonusers, and the fiscal benefits due to changes in rent. Thus, CATLAS provides an alternative to the noneconomic urban simulation models which do not have such capabilities and which are not estimated using rigorous econometric techniques, but by means of ad hoc and sometimes partly subjective goodness-of-fit procedures.

3. THE STRUCTURE AND PROPERTIES OF CATLAS

The purpose of this section is to present the basic mathematical structure and properties of CATLAS without going into a great deal of detail where such detail can be found in the literature dealing with the various techniques incorporated into CATLAS (see Anas, 1982; Duann, 1982).

3.1 Overall Recursive-Dynamic Structure

CATLAS consists of a number of equations to be solved simultaneously for each year in a simulation, while some of the variables entering these equations are adjusted recursively by being linked to the solution of the previous time period. Using general functional notation, the model's equations can be written as follows, where $t = 1\ldots T$ denotes the simulation year, $i = 1\ldots I$ the residential zones covering the metropolitan area and $h = 1\ldots H$ the categories of employment location (or zones of employment) and $m = 1\ldots M_i$ the number of modes available in zone i:

$$\sum_{h=1}^{H} N_h^t \sum_{m=1}^{M_i} \delta_i P_{im}^h (\overline{R}^t, \overline{X}^{Dt}, \overline{Y}_h^t, \overline{\alpha}_h) = S_i^t Q_i^e (R_i^t, \overline{X}_i^{St}, \overline{\beta});\ i = 1\ldots I, \tag{1}$$

$$S_i^t = S_i^{t-1} + C_i^{t-1} - D_i^{t-1};\quad i = 1\ldots I, \tag{2}$$

$$C_i^{t-1} = \left(\frac{L_i^{t-1}}{g_i}\right) Q_i^c (R_{is}^{t-1}, s = 1\ldots Z;\ \overline{X}^{St-1}, r, \overline{\gamma});\ i = 1\ldots I, \tag{3}$$

$$D_i^{t-1} = O_i^{t-1}\ Q_i^d (R_{is}^{t-1}, s = a_i^{t-1}\ldots Z;\ \overline{X}^{St-1}, r, \overline{\delta});\ i = 1\ldots I, \tag{4}$$

$$L_i^{t-1} = L_i^{t-2} - g_i\ C_i^{t-2} + g_i D_i^{t-2};\ i = 1\ldots I, \tag{5}$$

$$O_i^{t-1} = O_i^{t-2} - D_i^{t-2} + A_i^{t-2};\ i = 1\ldots I, \tag{6}$$

$$R_{is}^{t-1} = R_i^{t-1} + \theta(s - \{X_{i1}^{Dt-1} = X_{i1}^{St-1}\});\ i = 1\ldots I, \tag{7}$$

$$\overline{X}_i^{Dt} = f_1(\overline{X}_i^{Dt-1});\ i = 1\ldots I, \tag{8}$$

$$\overline{X}_i^{St} = f_2(\overline{X}_i^{St-1});\ i = 1\ldots I. \tag{9}$$

The equations in (1) are the crux of the model and are solved simultaneously for every simulation year t to obtain the values of the rent vector $\overline{R}^t = [\ R_1^t, R_2^t, \ldots, R_I^t\ ]$ where R_i^t is the average rent of the housing units in zone i during year t.[10] N_h^t is the number of commuters employed in location h at time t, δ_i is zone i's ratio of households to commuters and S_i^t the number of housing units in zone i at time t. The functions $P_{im}^h(\cdot)$ and $Q_i^e(\cdot)$ are the demand and supply side choice functions. $P_{im}^h(\cdot)$ represents a commuter's choice of residential zone i and travel mode m for the journey from work to home as a function of the rents, $\overline{R}^t$, of all the residential zones, a vector $\overline{X}^{Dt}$ describing characteristics of the residential zones, another vector $\overline{Y}_h^t$ describing travel related characteristics of the zones for travel mode m and employment location h and a vector $\overline{\alpha}_h$ of coefficients to be estimated. $P_{im}^h(\cdot)$ is the average probability with which a commuter employed at h will choose zone i and mode m, or the expected proportion of commuters employed in h choosing zone i and mode m. The function $Q_i^e(\cdot)$ is the probability that the average dwelling in zone i will be offered for rent by the owner given the ongoing average rent R_i^t, a vector of the zone's characteristics $\overline{X}_i^{St}$ relevant to the supply side, and $\overline{\beta}$ a vector of coefficients to be estimated. $Q_i^e(\cdot)$ also the expected proportion of the available dwellings S_i^t which will be offered for rent, $1 - Q_i^e(\cdot)$ being the expected proportion to remain vacant. Equation (1) states that expected demand equals expected supply in each of the i = 1...I zones and in each simulation year t = 1...T. It has been proven in Anas (1982) that given N_h^t, δ_i, $\overline{X}^{Dt}$, $\overline{Y}_h^t$, S_i^t, $\overline{X}_i^{St}$ $\overline{\alpha}_h$ and $\overline{\beta}$ the system of equations can be solved for a unique and stable equilibrium rent vector $\overline{R}^t$ which clears the market in that year t. The second set of equations states that the number of dwellings in year t-1 increases by the expected number of new dwellings constructed, C_i^t, less the number of old dwellings demolished, D_i^t ,during that year. Equations (3) give the expected number of dwellings to be built in year t-1 in zone i: L_i^{t-1} is the quantity of vacant land available in zone i and g_i the amount of land per dwelling allowable in zone i due to zoning regulations, (L_i^{t-1}/g_i) being the potential new dwellings that can be accommodated in zone i. $Q_i^c(\cdot)$ is the expected proportion of these potential dwellings that will be built in year t-1. This function is derived from the developer's profitability decision. It depends on the stream of annual rents per dwelling expected to accrue over the dwelling's lifetime Z, on the vector of supply side characteristics $\overline{X}^{St-1}$, the market interest rate r and $\overline{\gamma}$, a vector of coefficients to be estimated. Equations (4) estimate the number of demolitions, D_i^{t-1}, in year t-1. This is the number of old (over thirty years) dwellings, O_i^{t-1}, eligible for demolition multiplied by the expected proportion to be demolished $Q_i^d(\cdot)$. This expected proportion is a function of the stream of annual rentals that can be obtained from the average old dwelling in zone i over its remaining lifetime, the vector of supply side characteristics $\overline{X}^{St-1}$, the interest rate r and a vector of coefficients to be estimated, $\bar{\delta}$. The age of the average old dwelling in the zone is a_i^{t-1}. Equations (5) update the amount of vacant land in a zone by accounting for land taken up by new constructions and land released by demolitions. Equations (6) adjust the number of dwellings eligible for demolition by adding, A_i^{t-2} the number of dwellings aging into the over thirty years category and thus becoming eligible for demolition. A_i^{t-2} is calculated from a simple cohort-survival model for housing for each zone. Equation (7) shows how the average rent of dwellings s years old can be computed by making a linear adjustment to the average rent of zone i. This is done by estimating a depreciation coefficient θ and multiplying this by $s - X_{i1}^{Dt-1}$ or $s - X_{i1}^{St-1}$ where $X_{i1}^{Dt-1} = X_{i1}^{St-1}$ is the age of the average dwelling in zone i at time t-1 (in other words, the age of the average dwelling may be considered to be the first element in the vectors $\bar{X}^{Dt-1}$ and $\bar{X}^{St-1}$). Finally equations (8) and (9) adjust the values of some of the variables in these vectors. The changes in the age of the average dwelling is one of these adjustments.

Having discussed the overall simultaneous/recursive structure of CATLAS we can now turn to a more detailed discussion of the four behavioral submodels. These are (a) the demand submodel or the choice functions $P_{im}^h(\cdot)$, (b) the occupancy submodel or the offer function $Q_i^e(\cdot)$, (c) the new housing construction submodel or the function $Q_i^c(\cdot)$, (d) the old housing demolition submodel or the function $Q_i^d(\cdot)$. These submodels are discussed in the following three subsections. A unifying aspect of these four models is that they are all derived as multinomial logit models consistent with utility or profit maximization. The special form of multinomial logit models allows computational convenience while preserving theoretical integrity.

A flow chart of the model's simultaneous/recursive structure is shown in Figure 3.1.

3.2 The Demand Submodel

The choice problem of a commuter with a given workplace h, is to determine the geographic zone of residence location i, the mode of commuting m, and the exact dwelling k within zone i. It is assumed that commuters have nearly perfect knowledge of all choices (i, m, k) available to them. In particular all zones (i = 1 ...I), all available commuting modes in each zone ($m = 1 \ldots M_i$), and each dwelling in a zone ($k = 1 \ldots S_i$) are assumed to be possible choices for each commuter.

The attractiveness (or utility) of an alternative (i, m, k) for the average commuter employed in workplace h is given as,

$$\hat{U}^h_{imk} = U^h_i + U^h_{im} + U^h_{imk} + \varepsilon^h_{imk} \tag{10}$$

This equation states that attractiveness consists of four additively separable parts. The first part, U^h_i measures the part of attractiveness due to characteristics which vary by zone. These would be characteristics such as shopping availability, school quality and access, crime rates, various public services, distances to major metropolitan points etc. The second part U^h_{im} is the part of attractiveness due to characteristics which vary by zone and mode of commuting. These would be characteristics such as travel time and travel cost from h to i by mode m, availability of parking at transit stations etc. The third part U^h_{imk} includes the part of attractiveness which varies by zone i, mode m and dwelling k. These would be things like the chracteristics of the house (number of rooms, floor and yard space, rent etc.). In many cases when these characteristics are not observed for each dwelling but are known in the data as zone averages they will be included in U^h_i or combined with other characteristics in U^h_{im}. In fact in the Chicago data used for CATLAS all the characteristics are

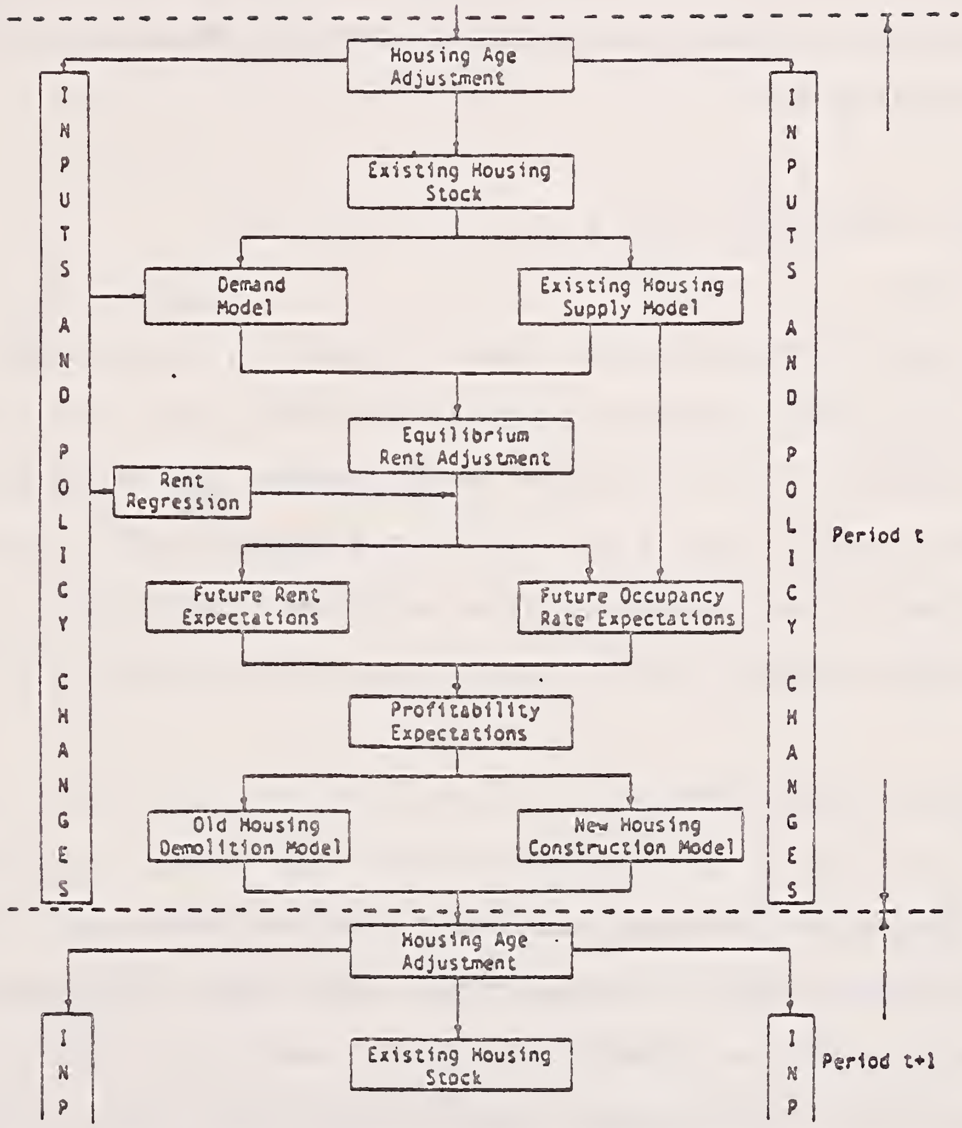


Figure 3.1: Flow Chart for the Simultaneous-Recursive Structure of CATLAS.

observed as averages for i or (i, m). Thus $U^h_{imk} = 0$ and it is as if all dwellings within the same zone are identical. The fourth part of attractiveness ε^h_{imk} is a random variable due to unknown (unobserved) characteristics including things like personal preference differences, random effects and errors in measurement. The probability that a commuter employed in h will choose (i, m, k) is given as,

$$P^h_{imk} = \text{Prob. } [\hat{U}^h_{imk} > \hat{U}^h_{jns}, \forall (j, n, s) \neq (i, m, k)] \qquad (11)$$

The specific form of (11) depends on what is assumed about the random terms, ε^h_{imk}. We follow the assumption that these error terms are correlated within zones (i.e. for different m and k within each i) but uncorrelated for different zones. Under this assumption the probability P^h_{imk} can be computed as the computationally tractable nested multinomial logit model. First, because utility is additively separable we can write the probability as,

$$P^h_{imk} = P^h_i \cdot P^h_{m|i} \cdot P^h_{k|im} \qquad (12)$$

Here $P^h_{k|im}$ is the conditional probability that the commuter will choose dwelling k, given that zone i and mode m have been chosen. $P^h_{m|i}$ is the conditional probability that the commuter will choose mode m given that zone i has been chosen and P^h_i is the marginal probability that zone i will be chosen. These probabilities are of the form

$$P^h_{k|im} = 1/S_i \, , \qquad (13)$$

$$P^h_{m|i} = \mathrm{EXP}(U^h_{im}) / \sum_{n=1}^{M_i} \mathrm{EXP}(U^h_{in}) \quad , \tag{14}$$

$$P^h_i = S_i^{\alpha_0^h}\, \mathrm{EXP}[U^h_i + (1 - \alpha^h_1) I^h_i] \;/\; \sum_{j=1}^{I} S_j^{\alpha_0^h}\, \mathrm{EXP}[U^h_j + (1 - \alpha^h_1) I^h_j] \quad , \tag{15}$$

$$I^h_j = \mathrm{LOG} \sum_{m=1}^{M_j} \mathrm{EXP}(U^h_{jm}) \quad , \tag{16}$$

$$U^h_{jm} = \alpha^h_2\, \mathrm{LOG}(R_j + C^h_{jm}) + \bar{\alpha}^h_3\, \bar{Y}^h_{jm},\; \alpha^h_2 < 0 \quad , \tag{17}$$

$$U^h_j = \bar{\alpha}^h_4\, \bar{X}^D_j \quad . \tag{18}$$

Equation (13) states that dwellings within a zone are equally likely to be chosen (because the data is not detailed enough to discriminate among them). Equation (14) states that the probability of choosing a mode m given the choice of zone is a multinomial logit model and thus depends on the relative attractiveness of the modes keeping zone characteristics constant. A property of this model is that the ratio of the probabilities of choosing modes m and n is simply

$$P^h_{m|i} / P^h_{n|i} = \mathrm{EXP}(U^h_{im} - U^h_{in}) \quad . \tag{19}$$

Equation (15) is the marginal zone choice probability and this is a nested logit model adjusted for zone size measured by the number of dwellings. The zone choice probability is a function of the zone's attractiveness plus a combined measure of the attractiveness measures of the modes in that zone. This is necessary because commuters consider the modes available in a zone as well as the attractiveness of the zone when they choose a zone. The combined measure of the zone's mode attractiveness (called an "inclusive value") is given by equation (16) and is in fact the logarithm of the denominator of the mode choice model (14). The coefficients α_0^h and α_1^h are among the other α's to be estimated statistically. The values of both of these coefficients should be found to be between zero and one. Their meaning is as follows: α_0^h is the measure of the similarity of dwellings in the same zone with respect to their unobserved attributes. If α_0^h is close to zero this implies dwellings within the same zone are nearly identical in unobserved attributes. At the other extreme if α_0^h is close to one, dwellings within the zone are nearly uncorrelated (dissimilar) in their unobserved attributes. The meaning of α_1^h is similar. If it is nearly one then the different modes are almost identical in their unobserved attributes, whereas if it is nearly zero then the modes are nearly uncorrelated in their unobserved attributes. Equations (17) and (18) specify the attractiveness functions as linear in the coefficients α_2^h and $\overline{\alpha}_3^h$, $\overline{\alpha}_4^h$ to be estimated together with α_0^h, α_1^h. Equation (17) states that the attractiveness of a zone-mode combination is a function of the average zone rent plus average travel cost for the mode and also a function of other zone characteristics, $\overline{Y}_{jm}^h$, which include travel time, distances to stations etc. (or the logarithms of such variables).

Multiplying (14) and (15) we can compute a joint probability P_{im}^h . This is the probability of choosing zone i and mode m given workplace h and it is this probability which is used as an expected proportion in equation (1) to compute the demand for zone i. Since all the zones are interconnected through the logit models a change in the attractiveness of a zone or the modes in that zone will have repercussions in the demand of all the other zones. For example, if the travel time of a mode (such as auto) for a zone improves, the probability of choosing that zone will increase (because it becomes more attractive) while the probability of choosing any other zone will decrease even though these decreases may be very small.

Clearly all of the above equations can be evaluated for each year t as the variables change. However, for simplicity I have suppressed the year subscript t from the notation.

3.3 The Occupancy or Existing Housing Supply Submodel

This submodel explains the choices of the owners of dwellings in the short run. The owner of an existing dwelling must decide whether to offer the dwelling for rent in that year or whether to withhold it until next year. The decision is based on profitability. Suppose that the average dwelling is offered for rent. Then it will yield a profit

$$\Pi_{i1} = R_i - M_{i1} + \varepsilon_{i1} \quad . \tag{20}$$

If it is kept vacant the loss is

$$\Pi_{i2} = -M_{i2} + \varepsilon_{i2} \quad . \tag{21}$$

Here R_i is the average rent in zone i, M_{i1} is the cost of maintaining the average dwelling if it is occupied and M_{i2} the cost of maintaining the average dwelling if it is vacant, and ε_{i1}, ε_{i2} are random measurement errors due to unobserved variables. Maintenance costs for occupied dwellings will be higher if the costs of repairs due to occupants exceed the costs of vandalism, neglect etc. for vacant dwellings. These will depend on the type and location of the dwelling's neighborhood. The differential profit is,

$$\Pi_{i1} - \Pi_{i2} = R_i - (M_{i1} - M_{i2}) + \varepsilon_{i1} - \varepsilon_{i2} \quad . \tag{22}$$

The differential maintenance cost is not directly available in the data but since it depends on neighborhood (i.e. zone) characteristics it can be made a function of these characteristics. Thus

$$(M_{i1} - M_{i2}) = \sum_{n=1}^{N} \beta_n X_{in}^S \quad , \quad . \tag{23}$$

where there are n = 1 . . . N supply side zone characteristics and the β_n's are the coefficients to be estimated. The probability that the average dwelling will be offered for rent can now be computed as,

$$Q_i^e = \text{Prob.}[\Pi_{i1} > \Pi_{i2}] \quad . \tag{24}$$

The simplest model consistent with (24) is the binary logit model. In this case this is,

$$Q_i^e = \frac{\text{EXP}(\beta_o R_i + \sum_{n=1}^{N} \beta_n X_{in}^S)}{1 + \text{EXP}(\beta_o R_i + \sum_{n=1}^{N} \beta_n X_{in}^S)} \quad , \tag{25}$$

where Q_i^e is the probability that the average dwelling will be offered for rent and 1 - Q_i^e the probability that it will be kept vacant. The coefficients to be estimated are β_o and β_1, . . ., β_N. The expected sign of β_o is positive since, if the going market rent R_i increases, the probability of offering the dwelling for rent should also increase because the profitability of occupancy increases. The probability Q_i^e is used as an expected proportion to compute the supply in equation (1).

3.4 The Housing Stock Adjustment Submodels

Housing stock adjustments occur yearly, but only the creation of new dwellings on vacant land and the demolition of old dwellings are considered. Both of these decisions depend crucially on the "present value of profits" (PVP) that can be derived from a dwelling over its remaining lifetime. Suppose that the average dwelling lasts Z years and let the age of the average dwelling in zone i be a_i. Then the present value of profits that accrue from rental decisions from now (time t) until Z can be computed as,

$$(PVP)_{tia_i} = \sum_{s=a_i}^{M} \frac{(R_{is}^{t} - M_{i1s}^{t})Q_{is}^{et} + (-M_{i2s}^{t})(1 - Q_{is}^{et})}{(1 + r)^{s-a_i}} \quad . \tag{26}$$

The numerator measures the "expected annual profit anticipated in the current year t for the year when the dwelling is s years old." Q_{is}^{et} is the probability that the dwelling will be rented when it is s years old, computed from the occupancy submodel. In the denominator, r is the market interest rate.

Now consider the owner of some vacant land parcel on which a dwelling can be constructed in zone i. This will be a new dwelling and thus s will run from one to Z in equation (26). Let K_{it} be the cost of constructing the dwelling, then the profit from construction will be,

$$\Pi_{ict} = (PVP)_{ti1} + J_{iM}/(1+r)^{Z} - K_{it} + \varepsilon_{it}^{c} \tag{27}$$

where J_{iM} is the resale value of the constructed dwelling Z years from now and K_{it} is the current cost of constructing the dwelling, ε^{c}_{it} being a random error term. If the land is kept vacant the profits will be equal to the land's price with the present value of all future taxes and other expenses to be incurred on the land capitalized into the price. Thus,

$$\Pi_{iot} = V_{it} + \varepsilon^{o}_{it} , \tag{28}$$

where V_{it} is the land price, ε^{o}_{it} being a random error term.

The present value of profits in equation (27) can be rewritten as

$$(PVP)_{til} = \sum_{s=1}^{Z} \frac{R^{t}_{is} Q^{et}_{is}}{(1+r)^{s-1}} + \sum_{s=1}^{Z} \frac{(M^{t}_{i2s} - M^{t}_{i1s}) Q^{et}_{is} - M^{t}_{i2s}}{(1+r)^{s-1}} , \tag{29}$$

where the first summation is the "present value of lifetime expected revenue" abbreviated as $(PVR)_{til}$. Differential profits can now be written as,

$$\Pi_{ict} - \Pi_{iot} = (PVR)_{til} + \sum_{n=1}^{N} \gamma_n X^{St}_{in} + \varepsilon^{c}_{it} - \varepsilon^{o}_{it} \tag{30}$$

where the summation stands for the second summation in (29) plus V_{it} which cannot be independently observed in the data. Thus these quantities are made a function of the supply side variables X^{St}_{in} and γ_n, n=1. . . N are coefficients to be estimated. Under these assumptions the probability that a vacant land parcel will be developed can be derived as a binary logit model of the form,

$$Q_i^{ct} = \frac{\mathrm{EXP}[\gamma_0(PVR)_{ti1} + \sum_{n=1}^{N} \gamma_n X_{in}^{St}]}{1 + \mathrm{EXP}[\gamma_0(PVR)_{ti1} + \sum_{n=1}^{N} \gamma_n X_{in}^{St}]} . \qquad (31)$$

This probability is entered as an expected proportion into equation (3).

The case of demolishing an old dwelling involves a similar reasoning. In this case the present value of profits from the dwelling's remaining future plus the demolition cost must be smaller than the present value of profits that can be derived from the vacant land which is created. In this case the probability of demolishing the average old dwelling in zone i is given by the binary logit model

$$Q_i^{dt} = \frac{1}{1 + \mathrm{EXP}[\delta_0(PVR)_{ti} + \sum_{n=1}^{N} \delta_n X_{in}^{st}]} , \qquad (32)$$

where $(PVR)_{ti}$ is the "present value of revenue over the remaining lifetime of the average old dwelling in zone i". The δ's are coefficients to be estimated.

3.5 Market Clearing Equilibrium at Each Year

As discussed before, the crux of the model is given by the simultaneous equations (1) which are solved for the market clearing rent vector $\overline{R}^t = [R_1^t, R_2^t, \ldots, R_I^t]$ at each year t. For convenience, these equations are rewritten as

$$\sum_{h=1}^{H} N_h^t \sum_{m=1}^{M_i} \delta_i P_{im}^h(\overline{R}^t, \overline{X}^{Dt}, \overline{C}^{th}, \overline{T}^{th}, \overline{Y}^{th}, \overline{\alpha}_h) = S_i^t Q_i^e(R_i^t, \overline{X}^{St}, \overline{\beta}) . \qquad (33)$$

The vectors $\overline{C}^{th}$, $\overline{T}^{th}$, and $\overline{Y}^{th}$ contain the travel cost, travel time and other transportation system characteristics (such as station locations, parking availability, etc.). Graphically, the equilibrium of demand and supply expressed by equations (33) is shown in figure 3.2. Changes in the transportation system will shift the demand function of all the zones either to the right or to the left depending on whether the zone is made more or less attractive by the change. Excess demands are observed in the zones where the demand function shifts to the right and excess supply where the function shifts to the left. The initial rents will increase in the zones where the demand function shifts to the right (the case of figure 3.2) and will decrease in the zones where the demand function shifts to the left. When the initial rents change, further shifts in the demand functions of all the zones will occur. These will cause further rent changes and the process will continue until it converges to an equilibrium. It is proven in Anas (1982) that equations (33) yield a unique equilibrium solution except possibly in the very unusual case when the rent of one or more zones are zero. This case should not be encountered in a meaningful empirical application and is thus not troublesome. It is also proven that the unique equilibrium is globally stable except for very large shifts in rents. Stability in this context means that if some rents are changed so that the system moves out of equilibrium it will return to it.

Anas (1982) also discusses a computational algorithm for solving the system of equations and finding the equilibrium zone rents. This algorithm is the one used in CATLAS to obtain the results to be reported in section 5.

3.6 <u>Measures of Economic Benefit: Consumer and Producer Surplus</u>

There are two kinds of economic benefit associated with transportation system changes that impact the housing and land markets. The first, <u>consumer surplus</u>, measures the benefit which accrues to households or commuters. This includes the direct benefit from changes in travel times and costs and also any benefit or disbenefit due to changes in rent induced by the initial changes in

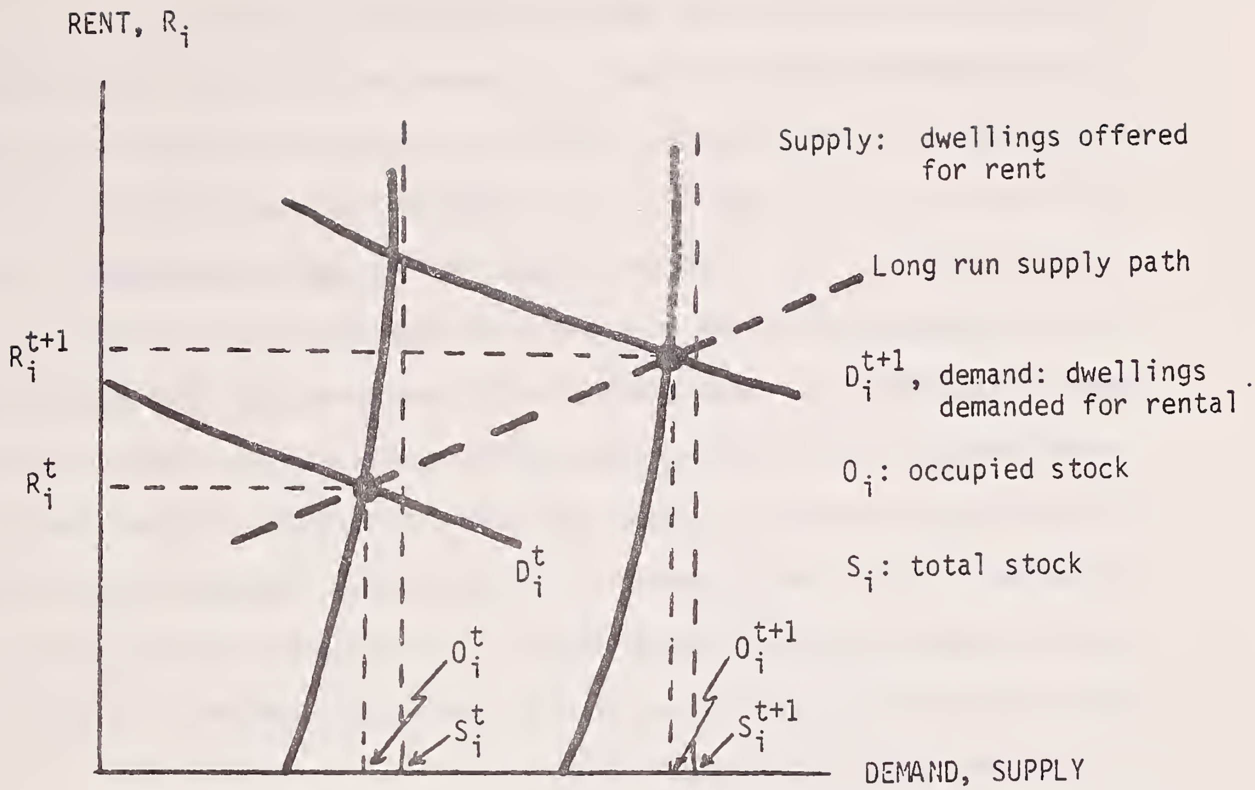
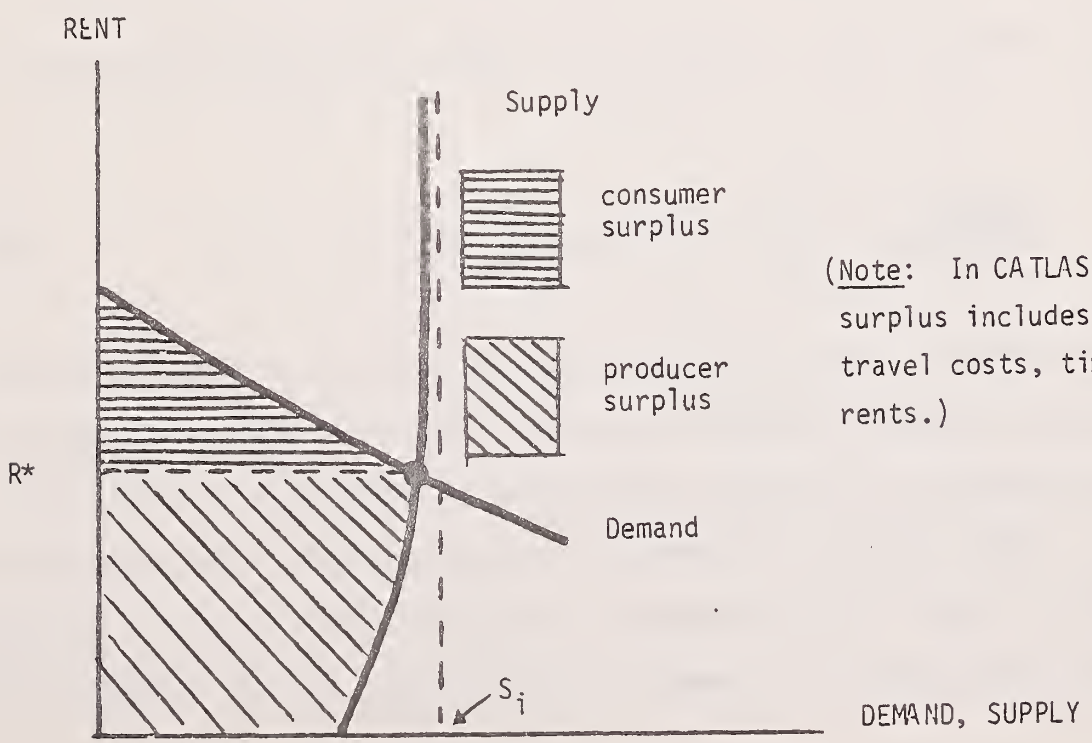


Figure 3.2: The equilibrium of the demand and the supply for dwellings and the determination of vacancies and rents in a zone i due to changes in the transportation system, which shift the demand function for the zone.



(Note: In CATLAS consumer surplus includes effect of travel costs, times and rents.)

Figure 3.3: Consumer Surplus and Producer Surplus Measures of Economic Benefit at Equilibrium

travel time and cost. The second, producer surplus, measures the profit after all maintenance costs accruing to the owners of dwellings. From economics (see Mishan (1960)), the producer surplus is a quasi-rent on the land occupied by dwellings and in a competitive land market is fully extractable as land rent by the landowners. Thus, producer surplus accrues to landowners who in general are not the same people as the households or commuters. It has been shown by Small and Rosen (1980) that when demand is measured by a logit type equation then consumer surplus is the area between the price paid and the demand function. Similarly producer surplus is the area below the price paid and above the supply function. In the case of multinomial logit models consumer surplus and producer surplus are easy to compute as shown in the article by Small and Rosen (1980). For example, the consumer surplus accruing to the commuters of the h^{th} workplace is the denominator of equation (15):

$$\begin{pmatrix}\text{CONSUMER} \\ \text{SURPLUS},h\end{pmatrix} = \sum_{j=1}^{I} S_j^{\alpha_o^h} \, \mathrm{EXP}[I_j^h + (1 - \alpha_1^h) \, \mathrm{LOG} \sum_{m=1}^{M_j} \mathrm{EXP}(U_{jm}^h)] \qquad (34)$$

The producer surplus accruing to the supply side, to housing owners in zone i is:

$$\begin{pmatrix}\text{PRODUCER} \\ \text{SURPLUS},i\end{pmatrix} = \sum_{i=1}^{I} [1 + \mathrm{EXP}(\beta_o R_i + \sum_{n=1}^{N} \beta_n X_{in}^s)] . \qquad (35)$$

The consumer surplus measure is measured in units of utility and takes into account changes in travel cost, travel time, other utility attributes and rent simultaneously and not just rent as shown in the example of Figure 3.3.

Another measure of benefit is the aggregate rent level seen to be the area R^*O^* in figure 3.3. An increase in the sum of these areas over the appropriate zones represents an increase in the tax base of the relevant municipality (central city or suburb), and is thus a fiscal benefit measure. As we shall see in section five, a special assessment tax can be used to capture all of such an increase using the revenues toward the capital cost of the transportation improvement that caused the increase.

3.7 Steady State Behavior of CATLAS

An important aspect of dynamic tools such as CATLAS is their behavior at steady state. CATLAS produces changes in the housing stock and in the rent of each zone as well as in the age distribution of the housing stock by zone. If the inputs remain constant over time, then the annual predictions of CATLAS will converge to a long run steady state. In the long run the number of vacancies in each zone will be reduced to zero as excess dwellings which remain vacant year after year will become demolished. All other variables determined within the model will either converge to steady state values or will cycle around a steady state value (i.e. will converge to a limit cycle). Empirical illustrations of such behavior are provided in section five.

4. EMPIRICAL ESTIMATION

In this section we briefly discuss the data and how it was used to estimate the four submodels of CATLAS. The estimation results for these submodels are then presented and discussed.

4.1 Data, Sampling and Estimation

The demand and supply side submodels of CATLAS can be empirically calibrated using the U.S. Census of Population and Housing. In the Chicago application, the 1970 Census results were used because these were the most recent available. These data have been tabulated to a system of 4918 square zones of 1/2 mile by 1/2 mile covering the Chicago metropolitan area. Each zone of this grid system is called a quartersection. Transportation and travel characteristics data are available for the same zones and were obtained from the Chicago Area Transportation Study (CATS). The CATS data is aggregated to the traffic zone level which consists of one mile by one mile square zones in the city and larger zones in the suburbs. This zone system is shown in figure 4.1. A 2 mile by 2 mile area centered on Madison and State Streets is taken to be the Central Business District or CBD. This area includes the "Loop", Chicago's traditional business center but is more than three times in area and contains 19% of all the jobs in the metropolitan region.

The census data includes information on the housing, population and employment characteristics of each quartersection and on the number of commuters traveling from each quartersection to each other quartersection by each available mode. The CATS travel data contains information on travel times and costs of travel by each mode and on the location of transit stations and bus lines. These data are sufficient for the estimation of all the submodels. Because quartersections are small, models estimated from such data yield statistically accurate results with only slight aggregation error as explained in Anas (1981).

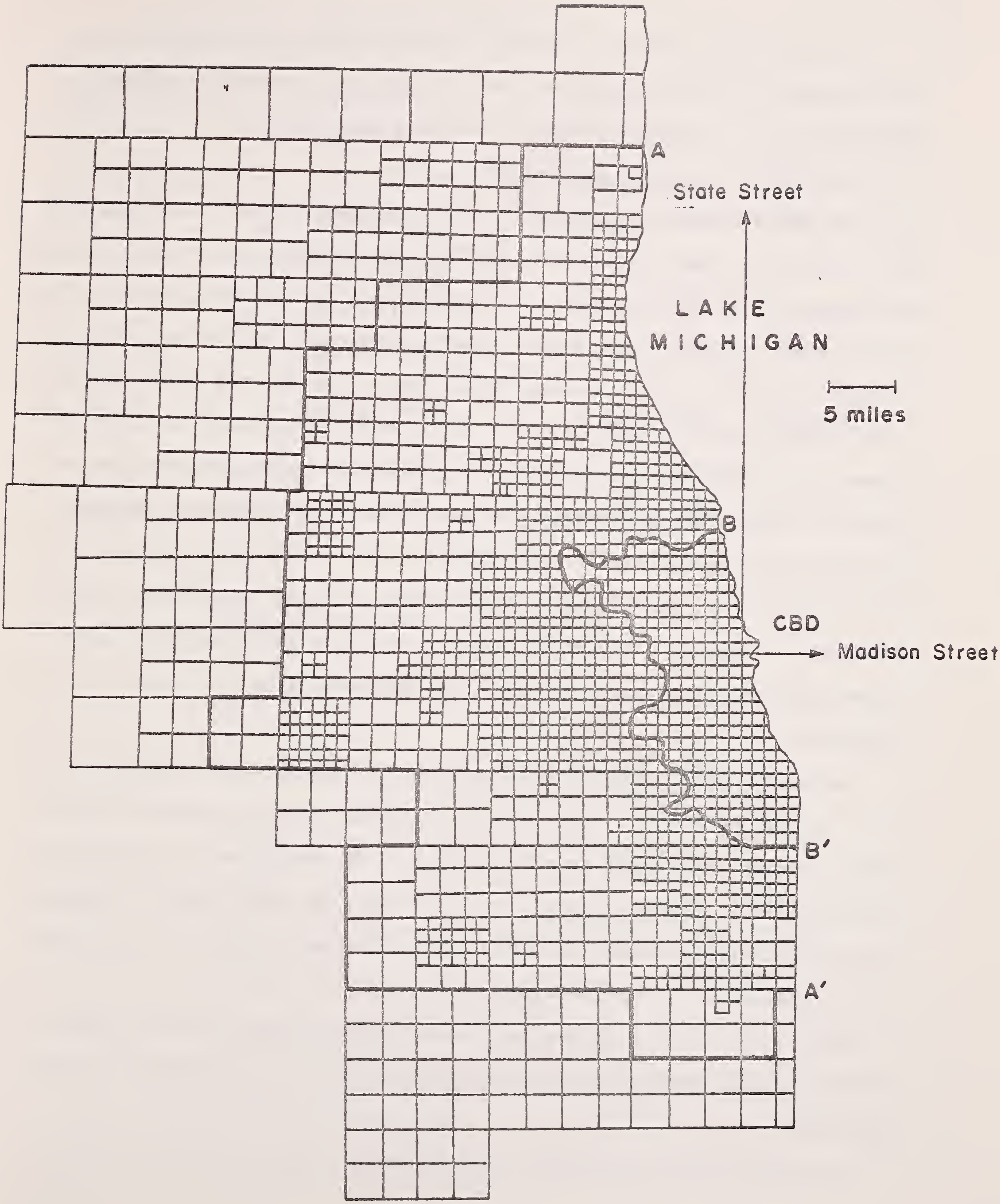


Figure 4.1: The Zone System for the Chicago SMSA

To estimate the submodels of CATLAS a random sample of 433 zones or nearly 9% of the total number of zones was selected and used. Maximum likelihood for aggregated data is the technique used to estimate these models.

4.2 <u>Estimation of Demand Submodels</u>

The demand submodels discussed in section 3.2 and consisting of equations (13) - (18) have been estimated for two workplace categories ($h = 1,2$). The first workplace ($h = 1$) is the two mile by two mile CBD and the second ($h = 2$) is all other employment dispersed throughout the rest of the Chicago SMSA (hereafter non-CBD). This dispersed "workplace" is represented by the average travel time and cost by each mode from each residential zone to all other employment zones excluding the CBD. This employment classification into CBD and non-CBD is appropriate only because CATLAS has been used to examine the impact of radial rail transit lines serving the CBD. These lines have almost all of their effects on CBD employment and these effects are quite insensitive to gross variations in dispersed non-CBD employment. Thus the above two-way classification goes a long way toward capturing the essential aspects of rail transit investment.

The actual modal choices of CBD and non-CBD commuters are shown in table 4.1. The CBD multinomial logit model is estimated with four modes of travel (auto, commuter rail, rapid transit and bus). The non-CBD model is estimated with two modes of travel (auto and bus). Al trips by other modes for CBD and non-CBD are treated as fixed in number for each residential zone and are added in as a constant to the left hand side of (1).

Table 4.2 lists the explanatory characteristics entered into the models, the value of each coefficient estimated and the t-statistic associated with that coefficient.

The housing supply coefficient, α_0^h, is forced to equal one and the inclus-

Location of Workplace

Travel Modes	Inside CBD	Outside CBD	Mode Totals
Auto driver	129,995 (29%)	1,184,372 (61%)	1,314,367 (55%)
Auto passenger	28,251 (6%)	230,598 (12%)	258,849 (11%)
Commuter rail	77,908 (17%)	26,665 (1%)	104,573 (4%)
Rapid transit	83,092 (18%)	38,849 (2%)	121,941 (5%)
Bus	108,400 (24%)	232,109 (12%)	340,509 (14%)
Other	26,050 (6%)	231,373 (12%)	257,423 (11%)
Total	453,696 (19%)	1,943,966 (81%)	2,397,662

TABLE 4.1 : Mode Choices of Chicago SMSA Commuters in 1970

Explanatory Characteristics in Utility Function	Estimated Coefficient CBD Model	Non-CBD Model
1. Housing supply	α_o = 1.000 (-)	1.000 (-)
2. Inclusive value	1 - α_1 = 0.723 (30.7)	0.955 (15.3)
3. Commuter rail (CR) dummy	α_2 = -.846 (23.0)	-
4. Rapid transit (RT) dummy	α_3 = -1.701 (39.0)	-
5. Bus dummy	α_4 = -0.636 (12.3)	-2.627 (175.0)
6. Log (Travel time)	α_5 = -2.392 (55.5)	-0.910 (25.7)
7. Log (Travel cost + rent)	α_6 = -1.488 (12.4)	-5.461 (42.6)
8. Bus miles/square mile	α_7 = 0.020 (54.4)	0.017 (70.5)
9. RT stations within 0-0.5 miles	α_8 = 0.294 (20.9)	-
10. RT stations within 0.5-1 miles	α_9 = 0.134 (9.9)	-
11. RT stations within 1-2 miles	α_{10}= 0.246 (23.2)	-
12. CR stations within 0-1 miles	α_{11}= 0.349 (19.9)	-
13. Log (Housing age)	α_{12}= -0.188 (14.0)	-0.097 (14.5)
14. Log (Zone income)	α_{13}= 1.015 (53.2)	-0.117 (8.4)
15. Log (Distance to the CBD)	α_{14}= 0.447 (18.4)	0.426 (47.9)
16. Log (Angle from Lake Michigan)	α_{15}= 0.001* (0.08)	-0.206 (23.0)
17. D1 (0-10 miles)	α_{16}= 0.490 (19.6)	0.287 (20.2)
18. D2 (10-20 miles)	α_{17}= 0.122 (6.0)	0.296 (29.9)
19. D3 (> 25 miles)	α_{18}= -0.591 (20.6)	0.132 (12.3)
20. Log (Rooms)	-	1.194 (62.0)
ρ^2	0.420	0.828

TABLE 4.2: Estimated coefficients and t-statistics of the CBD and non-CBD multinomial logit demand functions.

ive value coefficient in equation (15) is obtained to be between 0 and 1 as expected. Coefficients 3 through 10 are associated with the Y variables in mode choice shown in equation (17). Of these 3, 4, and 5 are mode dummy variables obtaining the value 1 for the relevant mode and the value 0 for other modes. The key characteristics are "travel time", "travel cost" and "rent". Characteristic 8 is the density of bus routes in a zone and 9-12 are the number of rapid transit and commuter rail stations within the indicated distance of a zone's center. Characteristics 11-18 are zonal averages which enter the zone utility given by equation (18). These are the $\bar{X}^D$ variables. They are the average housing age in the zone, the average income of zone residents in 1970 as a proxy of the zone's social prestige, the zone's distance to the CBD and the zone's angular displacement from the North Lake Michigan shore, and three zero-one dummy variables indicating the zone's location in four rings around the CBD (the "central city ring", of 0-10 miles, the "inner suburban ring" of 10-20 miles, the "outer suburban ring" of 20-25 miles and the "exurban ring" of 25+ miles). Finally the number of rooms in the average zonal dwelling are useful in explaining non-CBD choices and is entered into that model. All coefficients have the expected sign and are significant statistically with the exception of number 16 in the CBD model.

These characteristics, 13-20, have been selected after extensive and careful specification tests. Given the lack of data on the quality of schools, environmental amenities, shopping opportunities and the socioeconomic mix of neighoorhoods, it was necessary to use these proxy variables to capture a sense of locational amenities in the Chicago SMSA. Clearly, it is possible to compile better data and reestimate these models with direct (rather than proxy) variables. However, in the present study this is not necessary since these characteristics remain constant in the forecasting stage. Furthermore, the elasticities with respect to "travel cost", "travel time" and "rent", the three policy variables, are behaviorally valid as will be seen in subsection 4.4.

4.3 Estimation of Occupancy and Stock Adjustment Submodels

The occupancy, new housing construction and old housing demolition submodels discussed in section 3 have been estimated and the results are shown in table 4.3. Here PVR_{NEW} is the present value of the revenue expected to accrue to a new dwelling and PVR_{OLD} the present value of the revenue expected to accrue to an old dwelling over its remaining lifetime. Characteristics 4-16 are either dummy variables or zonal average measures proxying the cost sides of the occupancy, construction, and demolition decisions as explained in section 3. The occupancy and new construction submodels are estimated from the zonal data using maximum likelihood with the number of occupied units in each zone and the number of newly constructed units between 1969-1970 in each zone being known from the census. The number of dwellings demolished is not known by zone since it is not surveyed in the census. For this reason, the demolition submodel is estimated using a cruder method. The number of dwellings demolished in the entire Chicago SMSA in the 1960's is used to determine a crude annual metropolitan demolition rate. The model coefficients are then adjusted by trial and error to achieve a good fit to this aggregate demolition rate. For this reason standard errors (and t-statistics) cannot be computed for the demolition submodel.

4.4 Demand- and Supply-Side Elasticities

An important use of the estimated demand and supply side models is that they can be used to compute key elasticities. These elasticities give a sense of the model's responsiveness to changes in the key explanatory variables. The key variables in the demand submodels are "rent", "travel time" and "travel cost". It is these variables that are changed by a specific transportation

Explanatory Characteristics	Estimated Coefficients Occupancy (β's)	New Construction (γ's)	Demolition (δ's)
1. Annual rent	0.000131 (19.5)	-	-
2. PVR_{NEW}	-	0.00001018 (12.95)	-
3. PVR_{OLD}	-	-	0.00002135 (-)
4. Rental dummy	-0.679 (17.2)	-	-
5. Build dummy	-	2.214 (62.88)	-
6. Don't demolish dummy	-	-	4.595 (-)
7. City location dummy	-	-0.6162 (34.35)	-
8. Distance to CBD	-	-0.09660 (137.2)	-0.03853 (-)
9. Angle	0.00131 (19.9)	-0.003345 (35.51)	-0.001892 (-)
10. Rooms	-	-	-0.1135 (-)
11. Housing age	-	-	-0.0146 (-)
12. log(Housing age)	0.516 (53.0)	-	-
13. % Black Households	-0.00347 (32.2)	-0.007379 (30.94)	-0.002736 (-)
14. % Developed land	0.0119 (61.1)	-	-
15. % Single family housing	0.0181 (119.1)	0.0119 (61.1)	0.01137 (-)
16. Zonal income	-	0.00003756 (21.7)	0.00010326 (-)
ρ^2	0.981	0.835	-

Table 4.3: Estimated coefficients and t-statistics of the occupancy, new housing construction and old housing demolition submodels.

policy. These elasticities are computed as the weighted averages of the zone elasticities evaluated with the data from which the models are estimated.

The demand side elasticities are as follows:

Rent: A 1% increase in the rent of the average zone (keeping the rents of the other zones constant) results in a 0.3% decrease in the demand of CBD commuters for that zone and in a 0.2% decrease in the demand of non-CBD commuters.

Travel cost: A 1% increas in the travel cost to the average zone (keeping the costs of the other zones constant) results in a 0.25% decrease in the demand of CBD and non-CBD commuters for that zone.

Travel time: A 1% increase in the travel time to the average zone (keeping the times of other zones constant) results in a 1.7% decrease in the demand of CBD commuters to that zone and in a 0.25% decrease in the demand of non-CBD commuters to that zone.

Details on the computation of these elasticities can be found in Anas (1982). All of these elasticity estimates are very consistent with the findings by other scholars reported in the literature.

In the late sixties it was wrongly believed that the rent (or price) elasticity of housing demand was minus one (Muth, 1969). Since then better estimates have been confirmed many times. For example, Hanushek and Quigley (1980) used data from the Housing Allowance Demand Experiment and found that the price elasticity was -0.4. Friedman and Weinberg (1981) used the same data and found -0.2. Mayo (1981) reviewed the literature and concluded that the elasticity was well below minus one.

Gomez-Ibanez and Fauth (1980) after transfering the work of Charles River Associates Inc. (1976), Atherton Suhrbier and Jessiman (1975) and Train (1976) to Boston found travel cost elasticities ranging from -0.12 to -2.69, in-vehicle time elasticities ranging from -0.36 to -1.77 and out-of-vehicle elasticities ranging from -0.23 to -2.7.

The supply side elasticities computed from the occupancy and new housing construction submodels are as follows:

Vacancies: A 1% increase in a zone's average rent results in a 0.24% decrease in the number of dwellings kept vacant by the owners in that zone.

New construction: A 1% increase in the average zone's rent results in a 0.29% increase in the zone's housing stock in one year.

These estimates are consistent with those of deLeeuw and Ekanem (1971), Ozanne and Struyk (1978) and Smith (1976) which have been compared and reconciled in a recent article by Rydell (1982).

5. SIMULATIONS AND POLICY IMPLICATIONS

In this section we present and discuss the simulation results obtained from the application of CATLAS to evaluate rapid transit projects proposed for the Southwest side of Chicago. The results are rich in policy implications regarding transit financing and these are discussed in this section.

5.1 Simulation Data and Assumptions

For the purposes of performing equilibrium simulations with CATLAS the zones of the Chicago SMSA are aggregated to the 1690 traffic zones as shown in figure 5.1. The same figure also shows the boundary of the Southwest corridor expected to be impacted in a major way by the proposed transit projects. Figure 5.2 shows the alignment of existing commuter rail and rapid transit lines within the corridor and also the alignment of three alternative proposed rail lines: the Archer Avenue subway, the Gulf Mobile and Ohio right-of-way project and the Indiana Harbor Belt right-of-way project. The last two projects would be built on the rights-of-way of freight railroads known by the same name.

Introduction of any one of these rail projects would change the zone-to-CBD transit travel times and costs of the zones within the Southwest corridor. To compute these new times and costs we need to take into account the changed costs of access to the new rapid transit stations. This was done by adopting an access mode choice model developed for the Chicago area by Sajovec and Tahir (1976). This model allows access to stations by walking, bus and automobile. The access costs and times computed from this model are added to the station-to-CBD line haul times and the minimum time route is then computed for each zone. The costs and times of these zones are then entered into the demand model for the CBD, replacing the times and costs existing prior to the new project.

In the policy simulations to be reported, it is assumed that the new

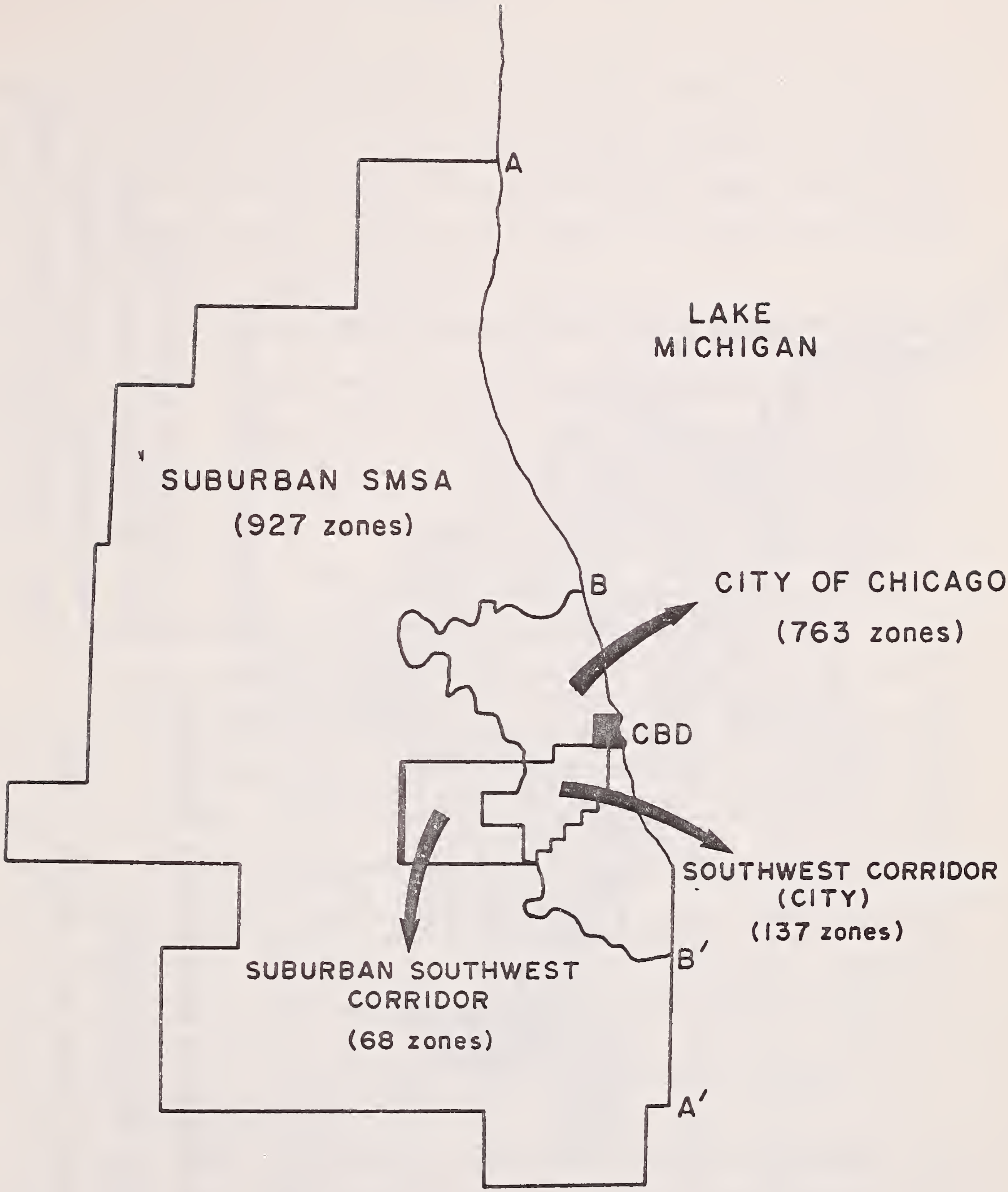


Figure 5.1 : The 1690 Zone System Used for Policy Simulations with CATLAS.

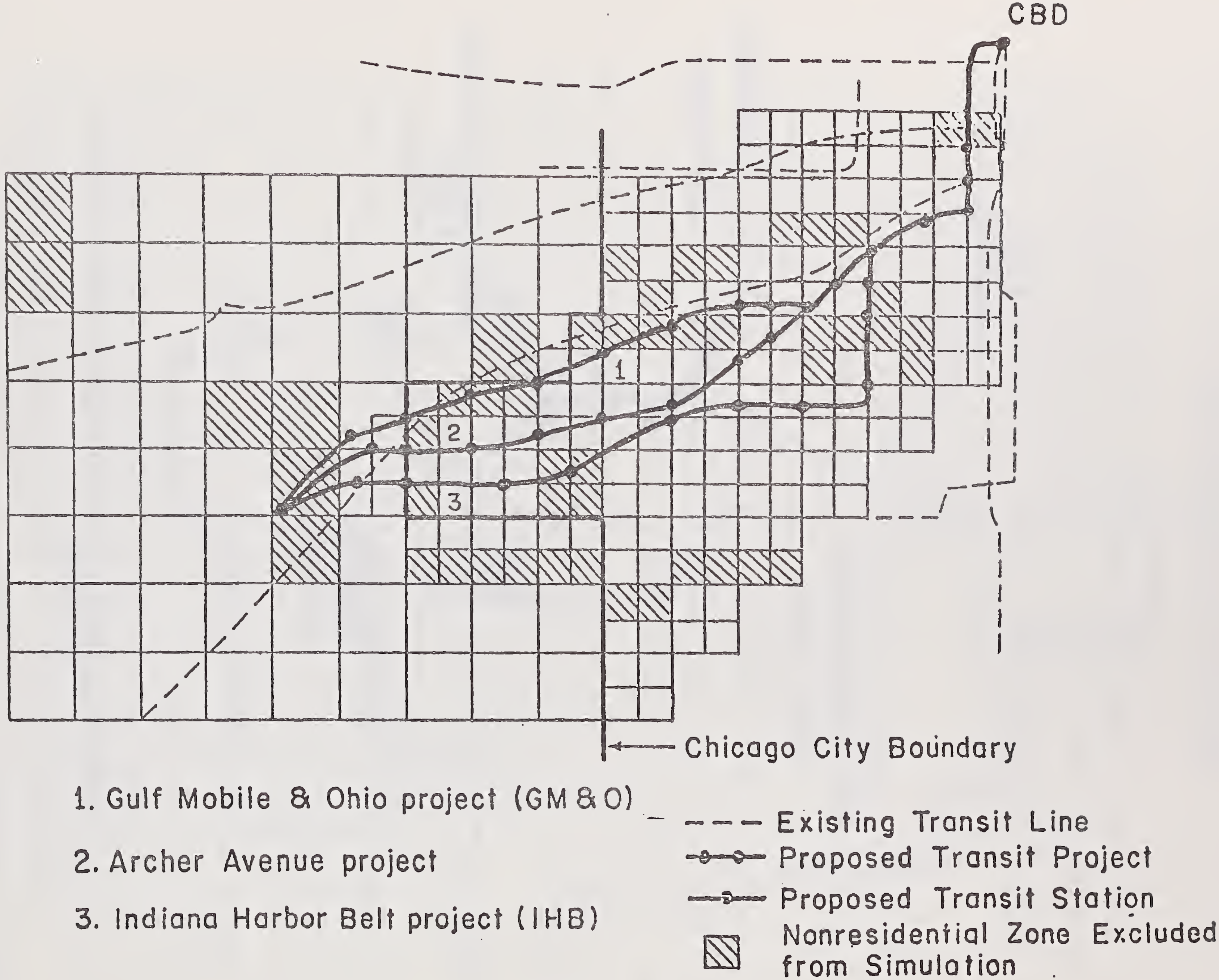


Figure 5.2 : Three Transit Projects Proposed for the Southwest Corridor.

transit projects will influence the decisions of CBD commuters only. Since in reality the transit project will draw trips from other employment locations as well, its impact on housing values and land use will be larger than that predicted in these simulations. In fact these results should be taken as lower bounds of the impact of the transit lines.

Tables 5.1 and 5.2 show the 1970 aggregate descriptive data for the Chicago SMSA and Southwest corridor respectively. The construction costs of the three rail projects were computed using detailed project descriptions and the unit costs from Permut and Zimring (1975) and Krueger et al. (1980). In 1970 dollars, the GM&O project would cost $120.4 million, the Archer subway $235.5 million ad the IHB project $249.1 million respectively.

5.2 Simulation Results and Transit Finance Implications

Two kinds of simulations are performed using CATLAS. The first of these is a static simulation in which the housing stock in each zone is held fixed at its 1970 level. This simply means that the housing stock adjustment submodels are removed from the recursive structure and the model deals ony with the allocation of households to dwellings by employing the demand and occupancy submodels. The second type of simulation uses the full recursive structure to simulate changes in the housing stock over time. For certain purposes the static simulations provide sufficient insight into certain basic results. Thus the results of these simulations will be presented first.

5.2.1 Static Simulations

Table 5.3 shows the effects of the three projects on aggregate rent changes, mode patronage (or demand) changes for CBD and non-CBD commuters and changes in consumer surplus. These can be looked at for the entire SMSA and for the Southwest corridor and by city and suburb in each case. The projects have the following effects: they increase the attractiveness or utility of central

HOUSING

	Rent ($/year)	Housing Stock	Vacant Units	Vacancy Rate (%)
CITY	1,859,632,333 (42.1)	1,197,370 (54.2)	70.344 (68.3)	5.87
SUBURBAN	2,556,541,980 (57.9)	1,013,781 (45.8)	32,682 (31.7)	3.22
Total	4,416,174,314 (100.0)	2,211,151 (100.0)	103,026 (100.0)	4.66

WORK TRIPS (daily, one-way)

	Auto	Computer rail	Rapid transit	Bus	Other	Total
CBD	158,246 (35.0)	77,908 (17.0)	83,092 (18.0)	108,400 (24.0)	26,050 (6.0)	453,696 (19.0)
Non-CBD	1,414,970 (73.0)	26,665 (1.0)	38,849 (2.0)	232,109 (12.0)	231,373 (12.0)	1,943,966 (81.0)
Total	1,573,216 (66.0)	104,573 (4.0)	191,492 (5.0)	340,509 (14.0)	257,423 (11.0)	2,397,662 (100.0)

TRAVEL TIME AND COST FOR WORK TRIPS (daily, one-way times (min); annual two-way costs, $)

	Auto	Commuter rail	Rapid transit	Bus	Total
CBD travel time	7,976,401	4,601,530	3,155,762	4,719,653	20,453,346
Non-CBD travel time	50,124,207	*	*	7,608,463	*
CBD travel cost	208,888,515	47,580,759	25,865,238	25,861,800	308,196,313
Non-CBD travel cost	1,559,869,108	*	*	52,400,825	*

TABLE 5.1 : Selected Aggregate Characteristics of the Metropolitan Data

HOUSING

	Rent ($/year)	Housing Stock	Vacant Units	Vacancy Rate (%)
CITY	232,506,706 (53.5%)	173,986 (66.8%)	8,382 (81.4%)	4.82
SUBURBAN	202,400,397 (46.5%)	86,662 (33.2%)	1,917 (18.6%)	2.21
Total	434,907,103 (100%)	260,648 (100%)	10,299 (100%)	3.95

WORK TRIPS (daily, one way)

	Auto	Commuter Rail	Rapid Transit	Bus	Other	Total
CBD	20,422 (38.6%)	5,689 (10.7%)	4,894 (38.6%)	20,502 (38.6%)	1,464 (2.8%)	52,991 (18.8%)
Non-CBD	159,196 (69.4%)	1,575 (0.7%)	2,132 (0.9%)	37,196 (16.2%)	29,193 (12.7%)	229,292 (81.2%)
Total	179,638 (63.6%)	7,264 (2.6%)	7,026 (2.5%)	57,698 (20/4%)	30,657 (10.9%)	282,283 (100%)

TRAVEL TIME AND COST FOR WORK TRIPS (daily, one-way times (min); annual two-way cost, $)

	Auto	Commuter Rail	Rapid Transit	Bus	Total
CBD travel time	957,842	270,167	206,895	830,690	2,265,594
Non-CBD travel time	5,858,183	*	*	1,243,073	7,101,256
CBD travel cost	19,471,295	2,739,071	1,607,423	4,637,050	28,454,839
Nib-CBD travel cost	146,705,281	*	*	8,369,100	155,074,381

GASOLINE CONSUMPTION FOR WORK TRIPS BY AUTO (daily, one way)

CBD auto trips	17,470 gallons
Non-CBD auto trips	98,666 gallons

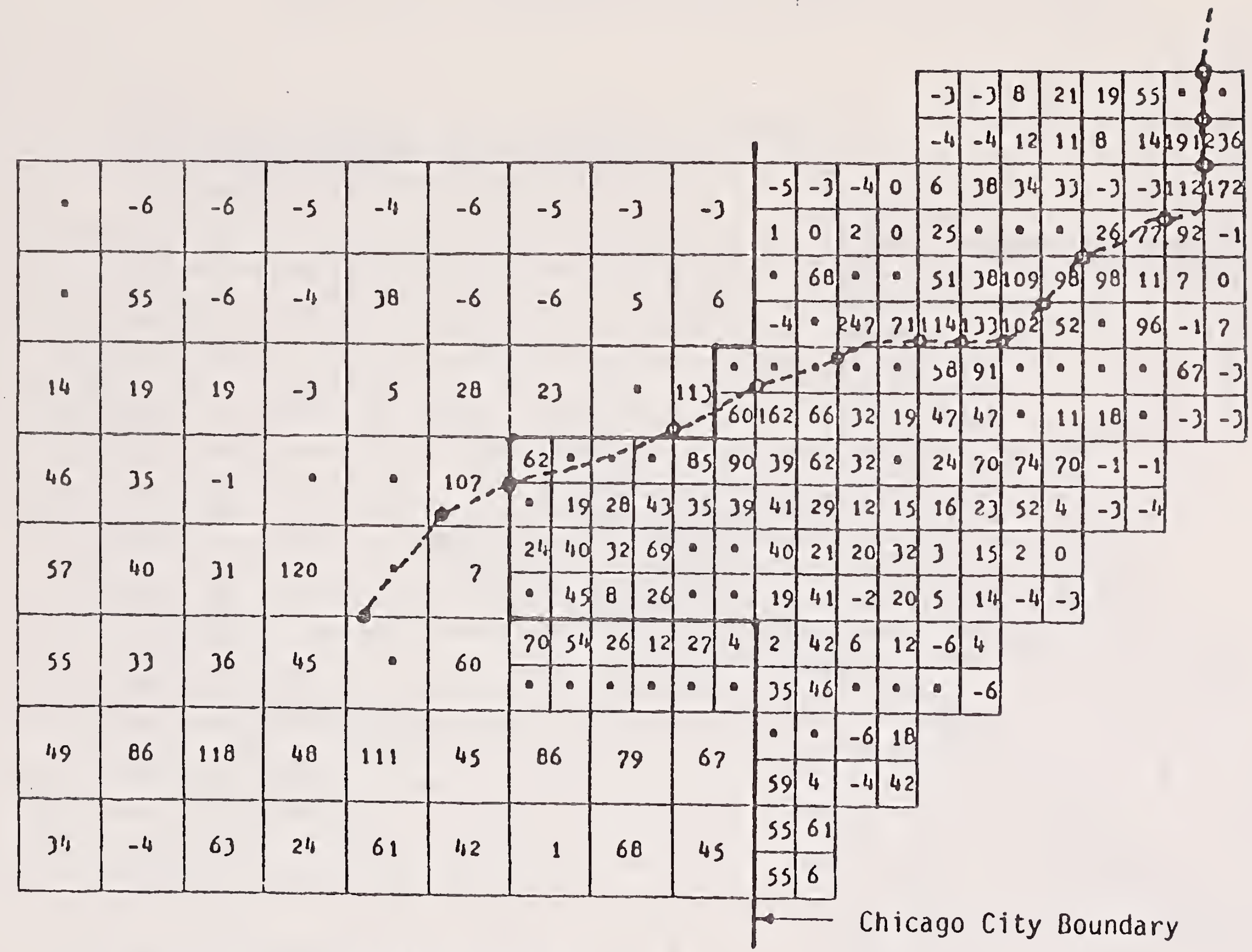
TABLE 5.2 : Selected Aggregate Characteristics of the Southwest Corridor Data

Project	% Aggregate Rent Change			%Mode Demand Changes CBD				Non-CBD		Employee Change[1]		Consumer Surplus[2]	
	City	Suburb	Total	Auto	Rail	Transit	Bus	Auto	Bus	CBD	Non-CBD	CBD	Non-CBD
Metropolitan Changes													
GM&O	0.003	-0.089	-0.051	-0.84	-0.29	3.59	-1.32	0.02	-0.15			2.3	-0.0074
ARCHER	0.033	-0.128	-0.060	-1.05	-0.32	4.50	-1.70	0.02	-0.15			2.9	-0.016
IHB	0.027	-0.115	-0.055	-1.01	-0.30	4.24	-1.57	0.02	-0.14			2.8	-0.017
Southwest Corridor Changes													
GM&O	2.14	0.72	1.48	-5.21	-2.12	62.45	-6.6	0.31	-2.66	516	-499	-	-
ARCHER	2.92	0.70	1.89	-6.45	-2.07	78.31	-8.5	0.33	-3.13	657	-634	-	-
IHB	2.73	0.73	1.80	-6.23	-1.91	73.79	-7.8	0.31	-2.96	622	-601	-	-

TABLE 5.3: Simulation Results for the Three Rail Projects

[1] Number of employees who relocate into or more out of the Southwest corridor Study Area

[2] $(\times 10^{-3})$



O Transit Station without Parking
● Transit Station with Parking
☐ Nonresidential Zone Excluded from Simulation

Figure 5.3: Average Zonal Rent Changes in the Southwest Corridor Due to the Gulf Mobile & Ohio Project.

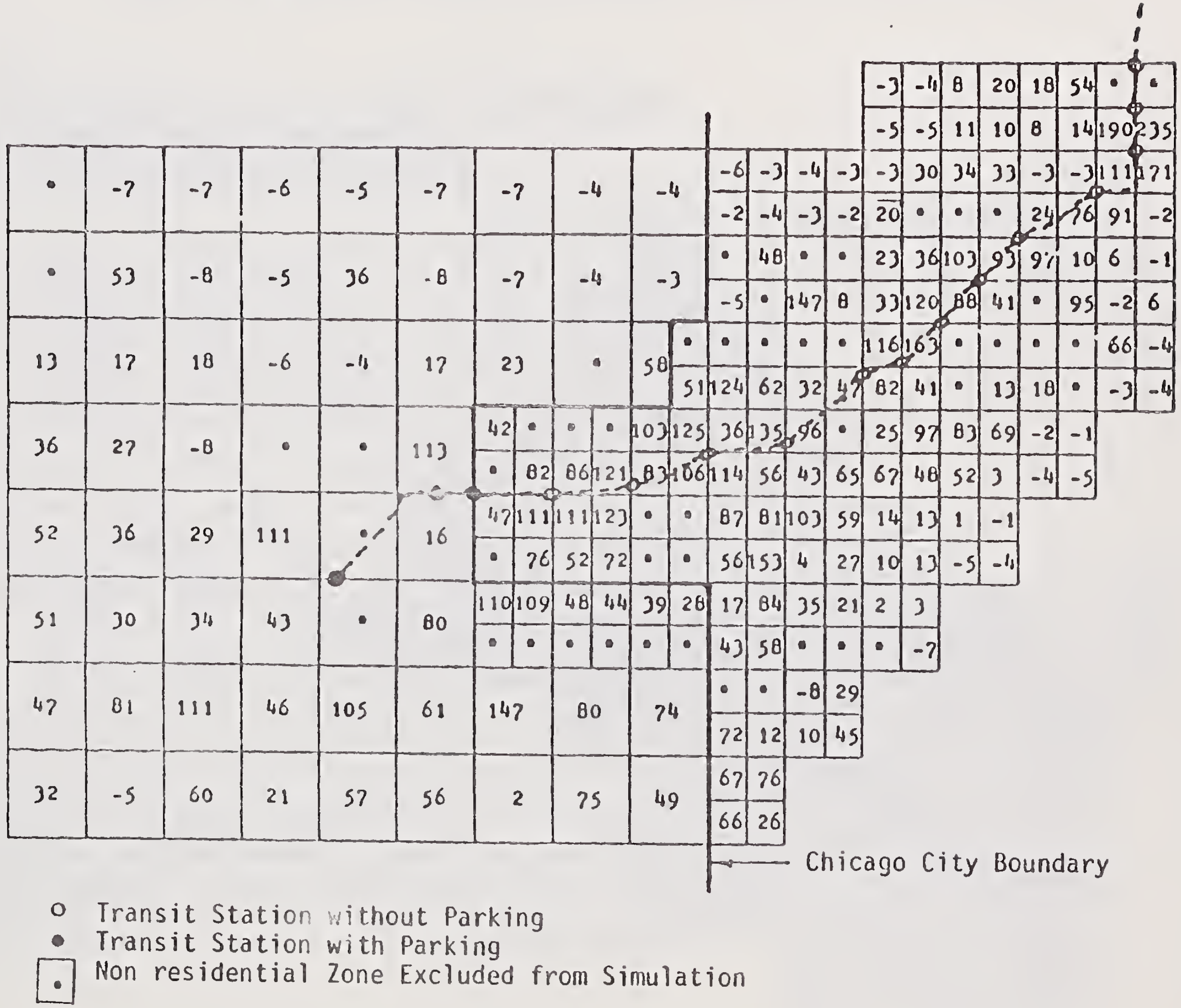


Figure 5.4: Average Zonal Rent Changes in the Southwest Corridor Due to the Archer Avenue Project.

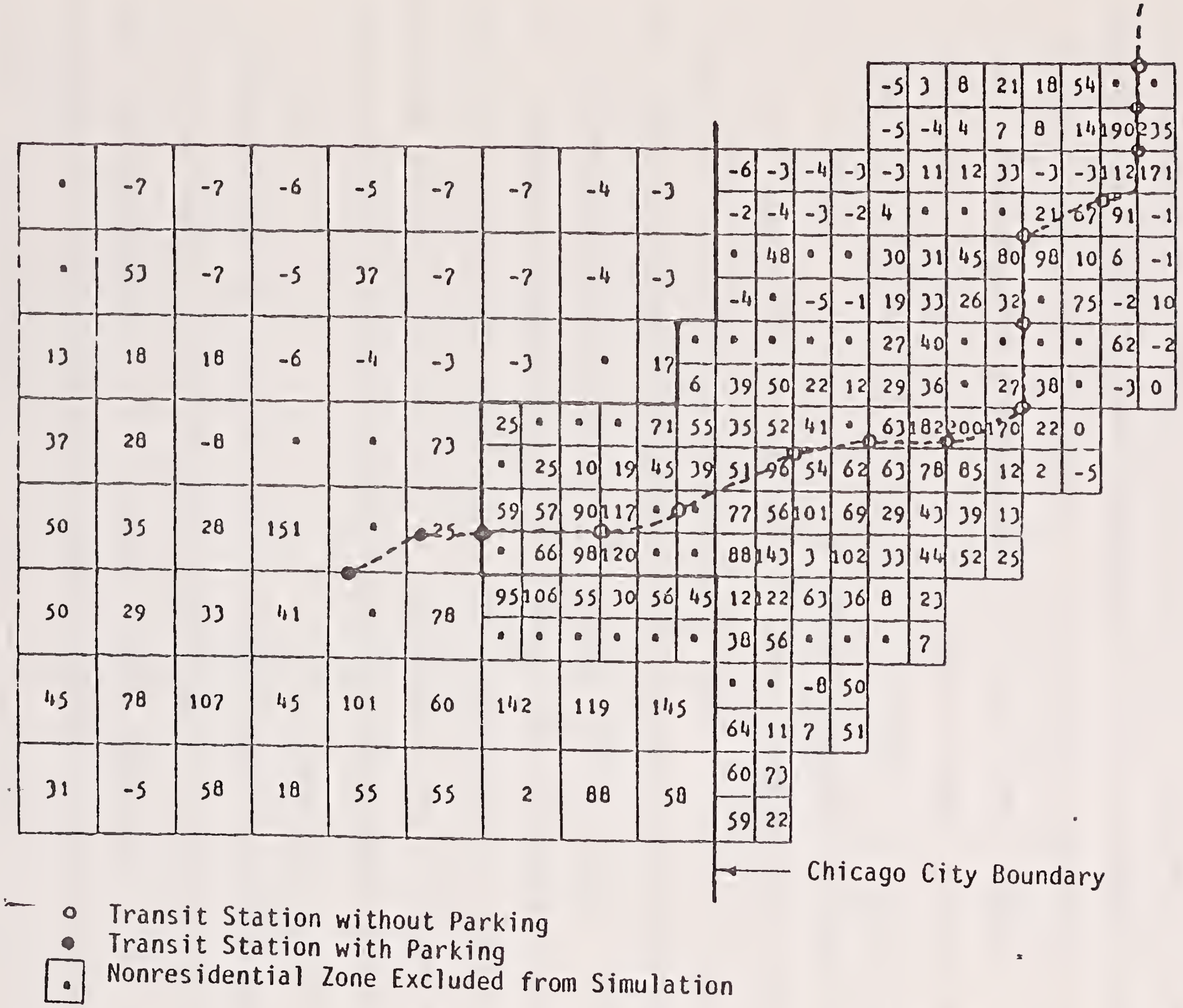


Figure 5.5: Average Zonal Rent Changes in the Southwest Corridor due to the Indiana Harbor Belt Project.

city zones by reducing transit travel times and costs and by extending such service to where it was not previously available. These effects are concentrated in the central city because most of the zones served by the project are central city zones. The effect is to attract some households to relocate from the suburbs to the city thus raising city rents while reducing suburban rents. Aggregate metropolitan rents are reduced because the movement of households is from the higher rent suburbs to the lower rent central cities. When we look into the Southwest corridor we see that aggregate rents increase in both the city and suburban parts of the corridor. A zone by zone view of these rent changes are shown in figures 5.3, 5.4, and 5.5 for the three projects. These projects decrease aggregate metropolitan rents by 0.051 - 0.060% but increase rents within the corridor by 1.48% - 1.89% which amounts to \$6.4 - \$8.2 million annually. Rent changes outside the Southwest corridor are extremely small in magnitude (amounting to several dollars per dwelling annually at most) and can be ignored from a taxation viewpoint. If the special assessment district is defined to coincide with the boundary of the corridor and an incremental special assessment tax is implemented within this corridor taxing away the increases from the dwellings which appreciate in value and giving rebates to dwellings which decline in value, the incremental revenue collected in this way amounts to \$6.4 - \$8.2 million annually.

A few words are needed about the exact form of the incremental tax. It should be assessed as a lump sum one- time tax using an appropriate interest rate to discount the annual rent increments over the lifetime of the project. The lump sum obtained in this way represents the net increase in housing value. The owner of the housing unit should be given the option to pay this all in one time or in annual "mini-mortgage payments" over a period of time. If the house is sold in the meantime, all of the remaining tax-debt would be due at the time of the sale and taken out of the owner's sales revenues. Such a procedure has two desirable characteristics. First, as long as the interest rate used in discounting is acceptable to housing owners, the incremental tax is Pareto preferred: it does not make housing owners worse off relative to their well-being before the investment because all of the increased property value created by the transit improvement is taxed away. Second, the lump sum tax does not distort housing values because it is paid entirely by the current owner and not by a future buyer. Therefore future buyers have no incentive to reduce their bids on the property. If instead of a lump sum tax, one were to raise the property tax rate following the transit improvement, then housing values would decline somewhat. Of course, an adjustment in the tax rate would be inappropriate for other reasons as well. The tax rate must be uniform within a municipality and cannot be confined to a special corridor, whereas special assessment increments are legally permissible subject to public hearings and court approval, and can be set by zone or individual dwelling.

How big is the tax burden of such a special assessment on the housing owners in the corridor? The maximum zonal average rent increases are $247, $235 and $235 per year from Figures 5.3-5.5 respectively, or about $20 per month. In the vast majority of zones, rent increases are a lot lower. The average rent increase per dwelling in the corridor is just under $25 per year for the GM&O project. These figures show that the tax burden on the average housing owner is small and thus a special assessment policy is not likely to encounter major political opposition if it is carefully explained to the public and if the potential for rent increases is carefully documented. We also see that where rents decrease the decreases are negligible and thus if no rebates are given to such housing owners there will be no political opposition.

The next question of policy interest is "what percentage of the capital cost of these transit lines can be captured via the incremental tax method?" The answer depends crucially on what interest rate is used in discounting the annual tax revenues. Moody's Bond Survey Record gave a Ba rating to the Chicago Transit Authority in 1970. Bonds issued in 1970 with a Ba rating generally paid 10% interest. Using this interest rate the project capital costs are annualized over a 35-year horizon and the annual operating costs are computed using a procedure of the Chicago Transit Authority (1980). Table 5.4 lists the various cost recovery ratios for the three projects. Fare revenues raise 19.8% to 24.4% of the operating cost whereas value capture (special assessment) taxation raises 27.7% to 36.1% of the capital cost. Together, fares and taxes raise 24.9% to 30.6% of the total annual cost.

5.2.2 Dynamic Simulations

The purpose of the dynamic simulations is to determine whether the policy implications of the static simulations hold up or are substantially altered by the introduction of the stock adjustment submodels. The results obtained from the dynamic simulations depend crucially on what assumptions are made regarding the increase of employment (and population) for the Chicago SMSA. The results are also sensitive to year-by-year changes in the input variables. Neither the input changes nor the employment levels can be forecast with any certainty, thus whatever answers are obtained from the dynamic simulations must be taken with some reservation and should be examined for qualitative and gross quantitative insights.

Because the time path of the input variables is uncertain, one approach to dynamic simulation is to keep these constant over time. If this is done, then the housing stock adjustment submodels will forecast the redistribution and ageing-renewal of a fixed total housing stock.

The following assumptions were employed:

Project	New Passengers (one way work trips to CBD)	Annual operating cost	Annual capital + operating cost	Annual value captured	Annual fare revenue	Annual fare revenue to operating cost ratio	Annual value captured to capital cost ratio	Annual value captured plus fare revenue to total cost ratio
ARCHER	3832	9,993.2	39,632.3	8,211.0	2,440.4	.244	.277	.269
IHB	3611	10,371.0	40,677.9	7,810.0	2,299.6	.222	.258	.249
GM&O	3057	9,828.9	27,418.2	6,446.0	1,946.8	.198	.361	.306

TABLE 5.4: Estimated cost and cost recovery ratios for the three projects in 1970 (All dollar valued items in thousands in 1970 dollars)

Year	Rent Change (%)[1]			Mode Demand Change (%)[1]						Housing Stock Change[2]			Consumer Surplus[1]	
				CBD				Non-CBD						
	City	Suburb	Total	Auto	Rail	Transit	Bus	Auto	Bus	City	Suburb	Total	CBD	Non-CBD
1	-2.19	1.87	0.16	0.58	2.96	0.24	0.07	0.82	0.79	-8580	26660	18080	0.0029	0.011
2	-1.63	5.49	2.49	1.44	5.22	0.10	-0.45	1.85	-1.40	-8793	21452	12659	-0.0042	0.015
3	-1.16	8.14	4.23	2.07	7.13	-0.06	-1.00	2.63	-3.27	-8480	17510	9030	-0.012	0.018
4	-0.99	9.83	5.28	2.46	8.76	-0.20	-1.51	3.19	-4.63	-80[illegible]	14438	6350	-0.018	0.019
5	-1.03	10.75	5.79	2.68	10.18	-0.33	-1.98	3.57	-5.58	-7714	12014	4301	-0.024	0.021
6	-1.23	11.12	5.92	2.77	11.42	-0.46	-2.42	3.82	-6.24	-7378	10079	2701	-0.030	0.021
7	-1.51	11.07	5.77	2.77	12.51	-0.58	-2.85	3.97	-6.70	-7083	8510	1427	-0.035	0.022
8	-2.14	10.37	5.10	2.62	13.50	-0.66	-3.20	3.99	-6.66	-6821	7231	410	-0.039	0.023
9	-2.65	9.60	4.44	2.44	14.38	-0.77	-3.57	3.96	-6.65	-6590	6139	-451	-0.044	0.023
10	-3.09	8.77	3.77	2.23	15.16	-0.89	-3.93	3.90	-6.64	-6391	5244	-1147	-0.048	0.022
11	-3.48	7.84	3.07	1.99	15.86	-1.02	-4.29	3.80	-6.60	-6205	4486	-1719	-0.052	0.022
12	-3.83	6.86	2.36	1.73	16.49	-1.15	-4.65	3.67	-6.52	-6028	3844	-2185	-0.057	0.021
13	-4.13	5.83	1.63	1.44	17.05	-1.29	-5.00	3.52	-6.42	-5871	3290	-2582	-0.060	0.020
14	-4.41	4.76	0.90	1.14	17.57	-1.43	-5.34	3.34	-6.27	-5725	2806	-2919	-0.065	0.019
15	-4.63	3.66	0.16	0.83	18.05	-1.58	-5.68	3.15	-6.11	-5600	2388	-3212	-0.069	0.018
16	-4.83	2.53	-0.57	0.50	18.48	-1.73	-6.01	2.93	-5.91	-5487	2005	-3482	-0.073	0.016
17	-4.97	1.38	-1.29	0.16	18.87	-1.89	-6.34	2.70	-5.67	-5390	1677	-3713	-0.076	0.015
18	-5.06	0.21	-2.01	-0.20	19.24	-2.04	-6.67	2.45	-5.40	-5299	1376	-3923	-0.080	0.014
19	-5.11	-0.98	-2.72	-0.57	19.57	-2.19	-6.98	2.18	-5.09	-5212	1100	-4111	-0.083	0.012
20	-5.07	-2.16	-3.39	-0.94	19.88	-2.36	-7.29	1.90	-4.75	-5129	856	-4273	-0.087	0.011

TABLE 5.5: Aggregate results of the twenty year baseline simulation for the metropolitan area.

[1] Changes compared to the initial period

[2] Changes from previous year

²Changes from previous year

Year	Rent Change (%)[1]			Mode Demand Change (%)[1]						Housing Stock Change[2]			Net Employee Change[1]	
				CBD				Non-CBD						
	City	Suburb	Total	Auto	Rail	Transit	Bus	Auto	Bus	City	Suburb	Total	CBD	Non-CBD
1	-2.63	-1.78	-2.23	-0.17	1.28	-0.21	0.06	-0.75	1.21	-1408	652	-335	41	-751
2	-2.38	-1.14	-1.80	0.15	2.12	-0.79	-0.47	-0.74	-1.10	-1469	520	-949	16	-1592
3	-2.25	-0.92	-1.64	0.32	2.84	-1.32	-1.00	-0.85	-3.03	-1418	393	-1025	-43	-2481
4	-2.45	-1.22	-1.88	0.33	3.47	-1.60	-1.48	-1.10	-4.38	-1362	297	-1065	-127	-3386
5	-2.88	-1.89	-2.42	0.22	4.04	-2.24	-1.92	-1.46	-5.28	-1309	222	-1087	-229	-4295
6	-3.46	-2.81	-3.16	0.01	4.56	-2.64	-2.33	-1.90	-5.86	-1259	164	-1095	-345	-5199
7	-4.12	-3.87	-4.01	-0.26	5.03	-3.02	-2.71	-2.37	-6.22	-1214	118	-1096	-471	-6093
8	-5.15	-5.35	-5.24	-0.65	5.50	-3.33	-3.02	-2.97	-6.03	-1173	82	-1092	-604	-6975
9	-6.05	-6.72	-6.36	-1.05	5.91	-3.66	-3.35	-3.55	-5.89	-1138	51	-1087	-744	-7845
10	-6.88	-8.05	-7.42	-1.46	6.28	-3.99	-3.68	-4.12	-5.76	-1103	27	-1076	-890	-8701
11	-7.65	-9.34	-8.44	-1.87	6.62	-4.32	-4.02	-4.68	-5.62	-1073	7	-1066	-1041	-9543
12	-8.39	-10.60	-9.42	-2.30	6.93	-4.64	-4.35	-5.23	-5.46	-1044	-9	-1053	-1194	-10370
13	-9.11	-11.83	-10.38	-2.73	7.22	-4.95	-4.69	-5.79	-5.27	-1017	-20	-1037	-1350	-11181
14	-9.80	-13.03	-11.31	-3.17	7.49	-5.27	-5.02	-6.34	-5.07	-993	-34	-1027	-1508	-11981
15	-10.48	-14.21	-12.21	-3.61	7.73	-5.58	-5.35	-6.88	-4.84	-971	-42	-1013	-1668	-12766
16	-11.14	-15.37	-13.11	-4.06	7.96	-5.88	-5.68	-7.44	-4.58	-953	-53	-1006	-1830	-13544
17	-11.79	-16.51	-13.99	-4.52	8.17	-6.18	-6.01	-7.98	-4.30	-933	-58	-992	-1992	-14308
18	-12.44	-17.65	-14.86	-4.98	8.37	-6.47	-6.33	-8.53	-3.98	-915	-69	-904	-2155	-15065
19	-13.08	-18.77	-15.72	-5.45	8.56	-6.76	-6.65	-9.09	-3.63	-903	-75	-978	-2319	-15814
20	-13.70	-19.86	-16.57	-5.92	8.73	-7.04	-6.96	-9.63	-3.26	-886	-80	-966	-2484	-16553

TABLE 5.6: Aggregate results of the twenty year simulation for the southwest corridor.

[1]changes compared to the initial period

[2]changes from pervious year

Year	Rent Change (%)[1]			Mode Demand Change (%)[1]						Housing Stock Change[2]			Consumer Surplus[2]	
				CBD				Non-CBD						
	City	Suburb	Total	Auto	Rail	Transit	Bus	Auto	Bus	City	Suburb	Total	CBD	Non-CBD[3]
1	0.05	-0.05	-0.01	-0.83	-0.30	3.60	-1.33	0.03	-0.20	0	0	0	0.0021	-0.793
2	0.06	-0.04	0.00	-0.83	-0.32	3.60	-1.33	0.03	-0.21	3	-5	-2	0.0021	-0.564
3	0.07	-0.03	0.01	-0.84	-0.32	3.60	-1.32	0.04	-0.22	5	-2	3	0.0021	-1.148
4	0.08	-0.03	0.01	-0.83	-0.32	3.60	-1.31	0.03	-0.22	5	0	5	0.0021	-1.223
5	0.07	-0.02	0.02	-0.83	-0.32	3.60	-1.31	0.04	-0.23	5	2	7	0.0020	-1.257
6	0.08	-0.03	0.02	-0.83	-0.33	3.60	-1.30	0.04	-0.23	5	2	7	0.0020	-1.268
7	0.08	-0.02	0.02	-0.84	-0.33	3.60	-1.30	0.04	-0.23	4	2	6	0.0020	-1.267
8	0.08	-0.02	0.03	-0.84	-0.33	3.59	-1.30	0.04	-0.23	4	2	6	0.0020	-1.271
9	0.08	-0.01	0.03	-0.84	-0.34	3.59	-1.29	0.04	-0.24	4	1	5	0.0020	-1.263
10	0.08	-0.02	0.03	-0.84	-0.34	3.60	-1.29	0.04	-0.24	3	1	4	0.0020	-1.252
11	0.08	-0.01	0.03	-0.84	-0.35	3.60	-1.29	0.04	-0.24	3	2	5	0.0020	-1.240
12	0.08	-0.01	0.02	-0.84	-0.35	3.59	-1.28	0.05	-0.25	2	1	3	0.0020	-1.229
13	0.07	-0.02	0.03	-0.83	-0.34	3.58	-1.28	0.04	-0.24	2	1	3	0.0020	-1.220
14	0.08	-0.01	0.02	-0.83	-0.35	3.58	-1.28	0.05	-0.26	4	1	5	0.0020	-1.221
15	0.07	-0.01	0.03	-0.83	-0.36	3.57	-1.28	0.04	-0.25	0	1	1	0.0020	-1.203
16	0.08	-0.01	0.03	-0.83	-0.36	3.57	-1.28	0.05	-0.25	1	1	2	0.0020	-1.201
17	0.07	-0.01	0.02	-0.83	-0.35	3.57	-1.27	0.04	-0.26	1	1	2	0.0020	-1.202
18	0.07	-0.01	0.02	-0.82	-0.36	3.56	-1.26	0.04	-0.26	1	1	2	0.0020	-1.202
19	0.08	0.00	0.03	-0.82	-0.36	3.55	-1.27	0.04	-0.26	0	1	1	0.0020	-1.203
20	0.07	-0.01	0.02	-0.82	-0.36	3.55	-1.26	0.04	-0.26	1	1	2	0.0020	-1.201

TABLE 5.7: Aggregate results of the twenty year simulation of the Gulf Mobile & Ohio project for the metropolitan area.

[1] changes compared to the initial period

[2] changes from previous year

Year	Rent Change (%)[1]			Mode Demand Change (%)[1]						Housing Stock Change[2]			Net Employee Change[2]	
				CBD				Non-CBD						
	City	Suburb	Total	Auto	Rail	Transit	Bus	Auto	Bus	City	Suburb	Total	CBD	Non-CBD
1	2.17	0.78	1.52	-5.13	-2.17	62.79	-6.64	0.33	-2.78	0	0	0	538	-505
2	2.20	0.82	1.56	-5.15	-2.20	62.82	-6.61	0.33	-2.72	16	6	22	543	-489
3	2.21	0.85	1.58	-5.16	-2.23	62.82	-6.57	0.32	-2.67	12	4	16	547	-476
4	2.21	0.87	1.59	-5.17	-2.25	62.81	-6.53	0.32	-2.64	12	3	15	551	-466
5	2.21	0.89	1.59	-5.19	-2.28	62.80	-6.50	0.32	-2.62	12	2	14	554	-456
6	2.20	0.89	1.59	-5.18	-2.30	62.80	-6.47	0.33	-2.61	10	2	12	557	-448
7	2.18	0.09	1.59	-5.18	-2.32	62.76	-6.45	0.33	-2.61	8	2	10	559	-441
8	2.17	0.90	1.57	-5.18	-2.35	62.75	-6.43	0.34	-2.62	7	1	8	562	-435
9	2.14	0.89	1.56	-5.17	-2.37	62.73	-6.41	0.34	-2.63	8	1	9	564	-430
10	2.13	0.89	1.55	-5.16	-2.39	62.70	-6.40	0.35	-2.66	6	1	7	566	-424
11	2.11	0.89	1.54	-5.16	-2.41	62.65	-6.38	0.36	-2.67	5	1	6	568	-419
12	2.09	0.89	1.53	-5.14	-2.43	62.59	-6.37	0.36	-2.68	5	1	6	568	-416
13	2.07	0.88	1.52	-5.14	-2.45	62.51	-6.35	0.37	-2.70	5	1	6	570	-412
14	2.05	0.80	1.51	-5.12	-2.47	62.45	-6.33	0.38	-2.71	4	1	5	570	-408
15	2.04	0.88	1.49	-5.12	-2.48	62.37	-6.32	0.38	-2.73	3	0	3	571	-407
16	2.01	0.87	1.48	-5.11	-2.50	62.28	-6.30	0.39	-2.75	2	0	2	572	-404
17	1.99	0.87	1.47	-5.09	-2.51	62.20	-6.28	0.39	-2.77	1	0	1	572	-402
18	1.90	0.87	1.46	-5.08	-2.53	62.10	-6.27	0.40	-2.79	1	0	1	572	-401
19	1.96	0.87	1.44	-5.07	-2.55	62.01	-6.25	0.41	-2.81	1	1	2	571	-400
20	1.94	0.86	1.44	-5.06	-2.57	61.91	-6.25	0.41	-2.83	1	0	1	5.1	-398

TABLE 5.8 : Aggregate results of the twenty year simulation of the Gulf Mobile & Ohio project for the southwest corridor.

[1]Changes compared to the initial period

[2]Changes from previous year

1) The aggregate number of households and commuters is determined within the model by assuming that the aggregate housing vacancy rate will stay at the 1970 level and the number of households will adjust year by year according to changes in the housing stock.

2) All other input variables remain at their 1970 levels.

3) The distribution of jobs between the CBD and the non-CBD locations maintain their 1970 proportions.

We believe these assumptions to be the most prudent given our limitations in forecasting the future paths of the input variables .

Given the above assumptions, we performed a twenty-year simulation (i.e. from 1970-1990)without introducing any changes in the transportation system (this is called a baseline simulation or base run) and a twenty-year simulation in which the GM&O project is introduced (this is called a policy simulation or policy run).

The results of these baseline and policy simulations are shown in tables 5.5-5.8 for both the entire SMSA and for the Southwest corridor.

The aggregate rent changes and other fluctuations are caused by two factors. The first is the change in total housing stock and the second the housing redistribution among the zones. For the SMSA results (table 5.5) the aggregate rent changes are larger than the housing stock changes in the first several years because the new housing constructed in the suburbs is more valuable and there are fewer housing units remaining in the city due to demolitions. Following the construction of new housing units, the available vacant land is reduced; thus fewer housing units can be constructed. In the meantime, as the old housing units age, more of them will be demolished. Beginning with the ninth year, the housing stock begins to decrease. When the pace of population increase starts to slow down, owners find that it is more difficult to rent or

Policy	Operating cost	Capital & operating cost	Rent value captured	Rent & land value captured	Fare revenue	Fare revenue to operating cost ratio	Total value captured to capital cost ratio	Total value captured plus fare revenue to total cost ratio
GM&O	104,271	280,165	70,518	71,049	20,705	.199	.404	.328
GM&O Project with doubled CBD parking cost	104,383	280,277	52,315	52,669	27,061	.259	.299	.284
GM&O project with doubled gasoline price	104,290	280,184	62,179	62,635	21,806	.209	.356	.301

TABLE 5.9: Estimated costs and cost recovery ratios for the three policies obtained from the Dynamic Simulations (All values and costs in thousands in 1970 dollars. Interest rate used in discounting annual values to obtain value captured is 10%)

sell dwellings and demand lower rents. This explains the decrease of aggregate rents in the later years. The results for the Southwest corridor (table 5.6) are similar to the SMSA results, but because the average housing age is higher and the available vacant land is less than in the SMSA, the housing stock within the corridor begins to decrease from the first year and so do the aggregate rents.

The results of the GM&O policy simulation are shown in tables 5.7 and 5.8 which document the difference between the policy simulation and the corresponding baseline simulation. The most notable result is that the transit project has a very small net influence on the housing stock changes. In other respects the results are similar to the static simulations.

Two other policies were also simulated. In one of these the GM&O project is introduced and it is assumed that CBD parking fees double. In the second, it is assumed that the price of gasoline doubles. The estimated cost and cost recovery ratios are shown in table 5.9. In obtaining these figures, it was assumed that the incremental special assessment tax would be levied on vacant land as well as on housing units. It can be seen that the aggregate land value change in the Southwest corridor due to the project is quite small because less than 8% of the available vacant land is within the corridor. The cost recovery ratios are quite close to those of the static simulations.

We conclude from these results that the value capture policy is worth pursuing because it can defray about 40% of the capital cost of the proposed project (an amount higher than the 36% obtained from the static simulations).

5.3 Caveats and Conclusions

Any large scale simulation analysis is not an exact science and is subject to numerous sources of error and bias. Most of these are inherent in the data and in the mathematical form and assumptions of the analysis. Such sources of error and bias are unavoidable. The best one can do is to gain an intuition for the magnitudes of these errors and biases by performing extensive sensitivity testing on the various aspects of the analysis system including the estimated coefficients and elasticities. Such sensitivity tests were performed and have been reported in Anas (1982) and Duann (1982). Despite the fact that results can change substantially if some coefficients are doubled or tripled or if some data has not been accurately measured, little reason exists to doubt the basic conclusions. For example, some sources of error would tend to raise the percent of value captured from the 40% which was estimated to 50% while others may lower it to 30%. The overall effect of the various sources of error remains uncertain but within reasonable margins. In the final analysis we remain confident in the general approach and method used because we cannot identify any systematic sources of bias that weaken our conclusions.

There are several strong qualitative arguments that the total impact of transit on property values is stronger than that estimated in our application. This means that our quantitative results may be better viewed as lower bounds. We know, for example, that if CATLAS is extended to deal with nonwork trips as well as with work trips, then the impacts of transit on housing values will be higher because travel cost and time savings in nonwork travel will be capitalized into housing values. Similarly, if the non-CBD workplaces are identified by exact location rather than lumped together into one category, there will be additional gains in work travel translated into housing price increases. Finally, if we include commercial and industrial properties into the analysis, we will find that these too, and especially commercial floor space, appreciates in value substantially. Thus 40% of capital cost captured from within the Southwest corridor can be substantially higher if these omitted interactions are included within the model.

Another caveat is that the value capture cost recovery ratio of bus systems is surely higher than that for rail. This does not necessarily occur because bus systems have a stronger impact on housing values, but because the rolling stock cost of bus systems is much lower than the construction and rolling stock cost of rail systems. Thus, it should not be surprising if a similar analysis were to yield a cost recovery ratio for bus systems of 100% or higher. Such a result is not very useful, however, because it is the finance of rapid rail systems, and particularly of their capital cost, that poses the major challenge in the years ahead. It is abundantly clear that these costs cannot be covered out of the farebox if reasonable levels of ridership are to be maintained. Incremental special assessment taxes on real estate appear to be a promising way of financing a significant part of the capital costs of rail systems.

FOOTNOTES

1. See Federal Register (1976), "Major Urban Mass Transportation Investments", Vol. 41, No. 185, September 22; Federal Register (1978), "Policy Toward Rail Transit", Vol. 43, No. 45, March 7; Federal Register (1979), "Urban Initiatives Program: Guidelines", Vol. 44, No. 70, April 10, all of the Department of Transportation, Urban Mass Transportation Administration, Washington, D.C. See also Committee Print 96-7 (1979), "Urban Rail Transit: How Can Its Development and Growth Shaping Potential Be Realized?", Subcommittee on the City of the Committee on Banking, Finance and Urban Affairs, U.S. House of Representatives, 96th Congress, First Session, U.S. Government Printing Office, Washington, D.C.

2. Krueger, C., Heramb, C., Kunze, B. and Gallery, M. (1980), "Southwest Transit Study, Phase I Report: Preliminary Alternatives Analysis", City of Chicago, Department of Public Works, Bureau of Transportation Planning and Programming and "Southwest Transity Study: Draft Environmental Impact Statement" (1982), City of Chicago, Department of Public Works and Urban Mass Transportation Administration, Washington, D.C.

3. Indeed, planners' beliefs in rail systems is surprising considering the poor economic and financial performance of BART (the Bay Area Rapid Transit) system in terms of ridership and impact on land use and property values. A careful analysis of BART's problems has been written by Webber (1976): "The BART Experience: What Have We Learned?" Proponents of rail systems in other cities would agree that BART's failure can be attributed to its unique characteristics and the unusual features of the Bay Area.

4. This literature is reviewed in section 2.

5. See Sharpe, C. (1974), "A Value Capture Policy, Volumes I-IV", Technical Report TST-75-82-85, United States Department of Transportation, Washington, D.C. Also see Hagman, D. and Misczynski, D. (eds.) (1978), "Windfalls for Wipeouts: Land Value Capture and Compensation", American Society of Planning Officials, Chicago, Illinois.

6. Economic models are reviewed in section 2.

7. Travel demand and related models are reviewed in section 2.

8. Other urban simulation models are reviewed in section 2.

9. CATLAS is currently operational on Northwestern University's CDC 6600.

10. This average zonal rent is defined as $R_i^t = f_i^t r_i^t + (1 - f_i^t) V_i^t/10$, where f_i^t is the proportion of the zone's occupied dwellings which are renter occupied in year t, r_i^t the annual rental and V_i^t the value of the owner occupied dwellings. Values are divided by ten to annualize them following a rule of thumb due to Shelton (1968) widely used by urban economists.

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